SHIPBOARD ELECTRICAL SYSTEMS

Prepared by

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PREFACE

The extensive use of electrical equipment on ships of the United States Navy has made it necessary for engineering officers to acquire a basic knowledge of electricity and its practical application aboard ship. The need for a text from which suitable electrical training courses can be prepared has become evident.

It is the purpose of this text to familiarize the student engineering officer with shipboard power and lighting systems and the major items of component equipment. Treatment of such a broad subject in a single volume is necessarily limited in scope and is not intended as supplementary or superseding material to any of the official publications prepared by the Bureau of Ships, manufacturers, and building yards.

CONTENTS

CHAPTER 1

REVIEW OF THE FUNDAMENTALS OF ELECTRICITY

Electrical Systems of Ships

Almost daily improvements in the highly specialized electrical systems that power the Navy's fighting ships present a real challenge to the engineering officer. Latest techniques and equipment call for greater skill and training. This means that he must broaden his knowledge of engineering and related fields to keep abreast of advances in his equipment. More than ever before, he must be thoroughly grounded in the basic principles of electricity and their practical application and be familiar with various types of electrical equipment. Since teaching others is an important part of his responsibility, he must supplement his theoretical knowledge with practical operating experience. These requirements are exacting but they must be met if he is to do an effective job of seeing that the power, lighting, and interior communication equipment under his supervision is properly operated, maintained, and repaired.

This manual will help the engineering officer keep abreast of developments in his particular field. It provides up-to-the-minute information on shipboard electrical systems under cognizance of the engineering department. These systems embrace a great variety of equipment essential to the operation of the ship. They can be divided into three major groups: power, lighting, and interior communication.

Power systems include the generators, switchboards, power panels, cables, and motor-control equipment which are necessary for the generation, distribution, and control of the power supply to motor-driven auxiliaries, lighting, interior-communication, radio, radar, and other electrical equipment.

The *lighting system* on naval vessels includes cables, distribution panels, and lamps and fixtures for general illumination, low-level illumination, and special applications, such as flight-deck lights and running, anchor, and signal lights.

The *interior-communication installation* comprises the greatest variety of equipment of any electrical installation under cognizance of the engineering department. It includes all equipment and interconnecting cable in the individual systems used for transmitting and receiving orders and information between stations within the ship. Interior-communication installations are described in a separate text.

This chapter contains a brief review of those fundamentals of electricity considered as necessary background for the operator of naval shipboard electric plants.

Definitions of Electrical Terms

Electromotive force (*emf*) (E or e) is the total force generated by the battery or dynamo. Electromotive force is the pressure that moves or tends to move electricity against the resistance of a conductor. The practical unit is the *volt*.

Potential difference (V) is the pressure in volts that causes the flow of current between two points of a circuit. For example, the potential difference or voltage drop across the terminals of a motor plus the voltage drop due to supply-line resistance plus the voltage drop due to internal resistance of the generator would be equal to the electromotive force

of the generator. The potential difference is any part of the electromotive force and may be considered as that part of the voltage expended in moving the current between any two points of a circuit.

Electrical resistance (R or r) is that property of an electric circuit which tends to prevent the flow of electric current and at the same time causes electrical energy to be converted into heat energy.

Current (I or i) is the rate at which electricity flows through a conductor or circuit. The practical unit, called the *ampere*, is a current of one coulomb per second.

Magnetomotive force (*mmf* or F) is the pressure that tends to drive the flux through the circuit and corresponds to electromotive force in the electric circuit. The practical unit is the *ampere turn*.

Magnetic flux (Φ) is the total number of lines of induction existing in a magnetic circuit and corresponds to current in the electric circuit. The centimeter-gram-second unit of flux is the *maxwell*.

Reluctance ($\mathcal{R}$) is the obstruction to magnetic flux and corresponds to resistance in the electric circuit. The unit of reluctance is that resistance to magnetic flux offered by a centimeter cube of air. As yet no name has been given to the unit of reluctance.

Inductance (L) is the capacity for electromagnetic induction possessed by an active circuit either on itself or on neighboring circuits. Inductance may be divided into two types, namely: self inductance and mutual inductance. The practical unit is the *henry* which applies to both types of inductance.

Capacitance (C), sometimes called permittance or electrostatic capacity, is the power of storing or holding an electric charge; the ratio of an electric charge on a conductor to the electric potential difference producing the charge. The practical unit is the *farad*.

Direct-Current Electrical Circuits

OHM'S LAW

The basic formula for electrical circuits is contained in Ohm's law which, expressed in equation form, is

$$E = IR$$

where E = applied voltage
I = current in amperes
R = resistance in ohms

SERIES CIRCUITS

When several conductors are connected end to end so that the same current flows through all of them, they are said to be connected in series. The resistances and batteries shown in figure 1 are connected in series. If the positive direction of current flow is as indicated by the arrow, the potential drop from a to b is

$$V_{ab} = IR_1 - E_1 + IR_2 - E_2 + IR_3 - E_3$$

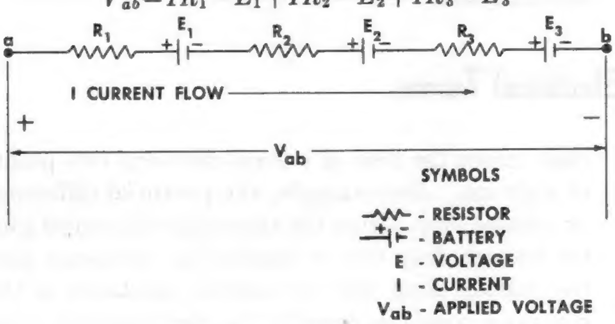

Figure 1.—Series circuit (d-c).

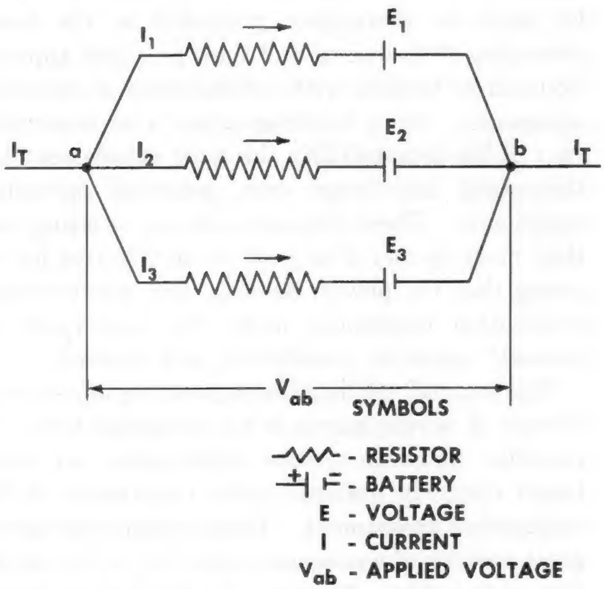

Figure 2.—Parallel circuit (d-c).

PARALLEL CIRCUITS

When several conductors are connected to two common junction points so that the same potential drop is established through each, they are said to be connected in parallel. In the parallel circuit of figure 2 the following relations exist:

$$I_T = I_1 + I_2 + I_3$$
$$V_{ab} = I_1R_1 - E_1 = I_2R_2 - E_2 = I_3R_3 - E_3$$

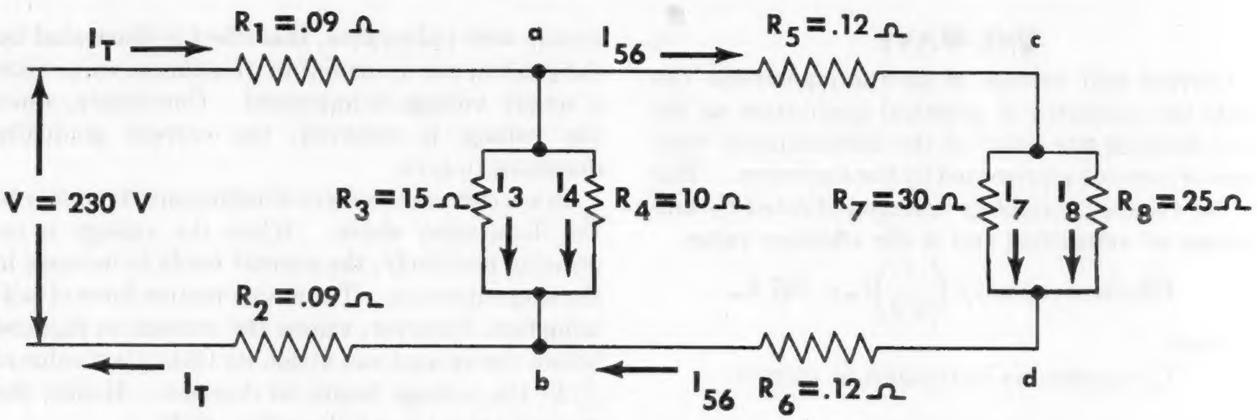

Figure 3.—Series-parallel circuit.

The direction of positive current flow in the different circuits is indicated by the arrows in figure 2.

If the batteries in the various branches are eliminated, the equivalent resistance from *a* to *b* is

$$R_{ab} = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$$

SERIES-PARALLEL CIRCUIT PROBLEM

Calculate the value of current in each line of the series-parallel-circuit shown in figure 3. The following steps show how this problem should be solved:

1. The equivalent resistance R_{e1} of the circuit including R_5, R_6, R_7, and R_8 is

$$R_{e1} = R_5 + R_6 + \frac{1}{\frac{1}{R_7}+\frac{1}{R_8}} = 13.84 \text{ ohms.}$$

2. The equivalent resistance R_{e2} of the circuit including R_3 and R_4 is

$$R_{e2} = \frac{1}{\frac{1}{R_3}+\frac{1}{R_4}} = 6 \text{ ohms.}$$

3. The total resistance R is

$$R = R_1 + R_2 + \frac{1}{\frac{1}{R_{e1}}+\frac{1}{R_{e2}}} = 4.368 \text{ ohms.}$$

4. $I_T = \frac{E}{R} = 52.65$ amperes.

5. $V_{ab} = E - I_T(R_1+R_2) = 220.53$ volts.

6. $I_3 = \frac{V_{ab}}{R_3} = 14.7$ amperes, and

$$I_4 = \frac{V_{ab}}{R_4} = 22.0 \text{ amperes.}$$

7. $I_{56} = I_T - (I_3 + I_4) = 15.89$ amperes.

8. $V_{cd} = V_{ab} - I_{56}(R_5+R_6) = 216.7$ volts.

9. $I_7 = \frac{V_{cd}}{R_7} = 7.22$ amperes.

$$I_8 = \frac{V_{cd}}{R_8} = 8.66 \text{ amperes.}$$

POWER

The practical unit of electrical power is the *watt*. One watt of power is produced in a direct-current circuit when 1 ampere of current flows with an impressed electromotive force of 1 volt. One watt equals 10^7 ergs per second. Power in d-c circuits may be calculated from

$$P = EI$$

POWER LOSS

When electric current passes through a resistance, a certain amount of energy is dissipated in the form of heat. This energy is lost for all practical purposes except when a resistance is actually used for heating.

The power loss in watts is given by the formula:

$$\text{Power loss} = I^2R$$

The amount of heat (H) developed in a period of time by a current passing through a resistance is given by:

$$H \text{ (in Btu)} = .0009480\ I^2RT$$

where T = time in seconds

Alternating Currents

SINE WAVE

Current and voltage of alternating-current circuits are evaluated in practical application as the root-mean-square value of the instantaneous voltages or currents represented by the sine wave. This is the value of current or voltage indicated by ammeters or voltmeters and is the effective value.

$$\text{Effective current} = \left(\frac{1}{\sqrt{2}}\right) I_m = .707\ I_m$$

where

I_m = maximum instantaneous current

FREQUENCY

A complete alternation of current or voltage through 360 electrical degrees is called a *cycle*, and the number of cycles per second is known as the *frequency*. Alternating-current systems aboard ships of the Navy are operated at the standard frequency of 60 cycles.

INDUCTANCE IN A-C CIRCUITS

A change in the magnitude of current in a circuit with inductance causes an electromotive force of self-induction which opposes this change. In a d-c circuit with inductance, this effect is illustrated by the gradual rise in current to its ultimate value after a steady voltage is impressed. Conversely, when the voltage is removed, the current gradually decreases to zero.

In a-c circuits the effect of inductance is similar to the illustration above. When the voltage is increasing positively, the current tends to increase in the same direction. The electromotive force of self-induction, however, causes the current to lag; and before the current can attain its Ohm's law value of E/R, the voltage begins to decrease. Hence, the current cannot reach the value, E/R.

In a circuit of pure inductance, the electromotive force of self-inductance is equal and opposite to the impressed electromotive force and the current lags the voltage by 90 electrical degrees. These relationships are shown in the sine curves of figure 4. (In actual practice it is impossible to obtain a pure inductance, as inductance is inherently accompanied with a certain amount of resistance.)

The choking effect of an inductance in limiting the magnitude of current in an a-c circuit is measured by $2\pi fL$ or the inductive reactance (X_L) expressed in ohms. In a circuit of pure inductance

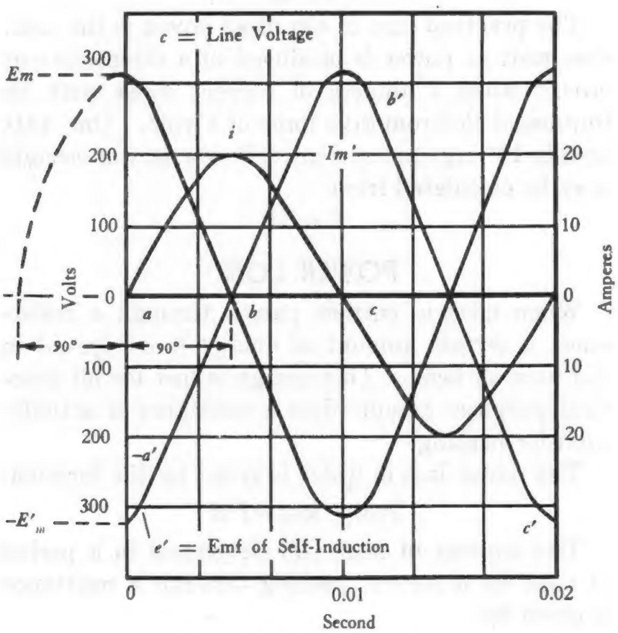

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Figure 4.—Current and voltage waves with inductance only.

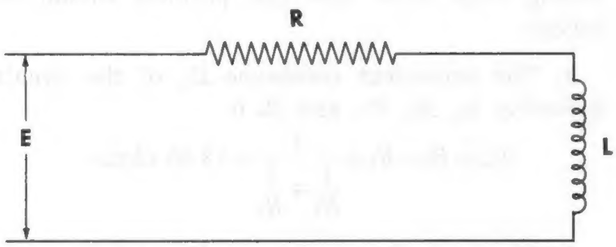

Figure 5.—Circuit with resistance and inductance in series.

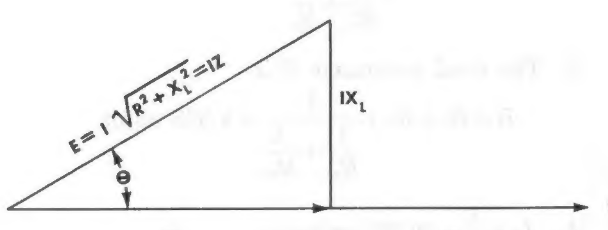

Figure 6.—Vector diagram for circuit with resistance and inductance in series

$$I=\frac{E}{X_L} \quad \text{or} \quad \frac{E}{2\pi fL}$$

In the circuit of figure 5, the voltage E_L across the inductance leads the current I by 90° and the voltage E_R across the resistance is in phase with the current.

This relationship can be represented vectorially as shown in figure 6.

The line voltage E is the vector sum of the voltages E_R and E_L and

$$E=\sqrt{(IR)^2+(IX_L)^2}$$
$$=\sqrt{I^2(R^2+X_L^2)}$$
$$=I\sqrt{R^2+X_L^2}$$

The quantity $\sqrt{R^2+X_L^2}$ is known as the impedance of the circuit, is expressed in ohms, and is denoted by Z. The current in the circuit can therefore be evaluated from the equation

$$I=\frac{E}{Z}$$

From figure 6 it can be seen that the current lags the voltage by an angle θ which can be calculated from either of the equations given below.

$$\text{Tan } \theta=\frac{X_L}{R}$$

$$\text{Cos } \theta=\frac{R}{Z}$$

POWER IN INDUCTIVE CIRCUITS

Pure inductance consumes no power. During those periods in which the current is increasing from zero to its maximum value, the energy received from the source is stored in the magnetic field of the inductance. Conversely, during the periods in which the current is decreasing from its maximum value to zero, all the energy stored by the inductance is returned to the source. Consequently, there is no expenditure of power in the inductance of a circuit. All power expended in a circuit of resistance and inductance is accounted for by the I^2R loss.

Power (P) in an a-c circuit with inductance and resistance may therefore be calculated from

$$P=I^2R$$

or from figure 6 by

$$P=E_RI$$
$$=EI\cos\theta$$

Cos θ is the *power factor* of the circuit. It is the ratio between the true power in watts and the apparent power in volt amperes.

$$\text{Power factor}=\cos\theta=\frac{P}{EI}$$

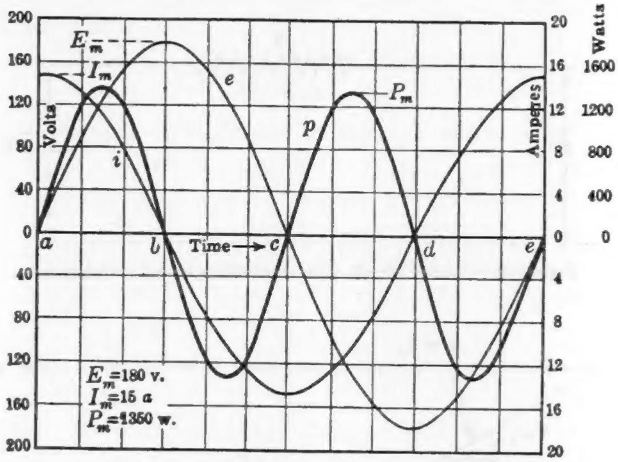

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Figure 7.—Voltage and current waves with capacitance only.

CAPACITANCE IN A-C CIRCUITS

If a voltage is impressed across the terminals of a perfect capacitor, current will flow until the capacitor is fully charged to the impressed voltage. This current is at a maximum when the voltage is first applied and decreases to zero as the capacitor comes up to full charge. There is no further flow of current if the voltage remains constant. If the terminals of the capacitor are short circuited, the capacitor will discharge and current will flow in a direction opposite to current flow under charging conditions.

In an a-c circuit consisting of pure capacitance, the relationship between impressed voltage and the current flowing into and out of the capacitor is shown in the sine curves of figure 7. As the impressed voltage increases from zero to a maximum, the current flow into the capacitor decreases from a maximum to zero. As the voltage decreases from a maximum to zero, the capacitor discharges with the current starting from zero and increasing to a maximum value. In this manner the current of an a-c circuit with capacitance follows an alternating sine-wave characteristic and leads the impressed voltage by 90°.

The value of a-c current that can flow in a circuit containing capacitance depends upon the capacity of the capacitance and the frequency of the applied voltage. This relationship may be expressed as

$$I=E(2\pi fC)$$

where C = capacity in farads

$$\text{or } I=\frac{E}{X_c}$$

$$\text{where } X_c=\frac{1}{2\pi fC}=\text{capacitive reactance}$$

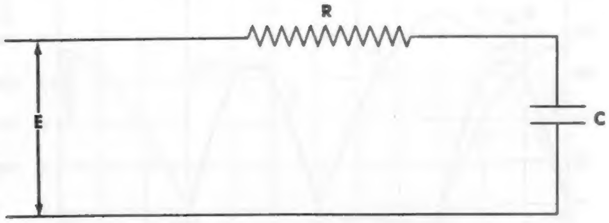


Figure 8.—Series circuit with capacitance and resistance.

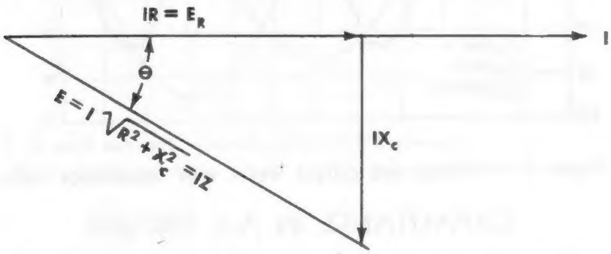


Figure 9.—Vector diagram for circuit with capacitance and resistance in series.

Figure 8 shows a resistance and capacitance connected in a series circuit. The relationships between applied voltage, voltage drops across resistance, and capacitance and line current are shown vectorially in figure 9. The line voltage E is the vector sum of IR and IX_c and where Z is the impedance of the circuit.

$$E=\sqrt{(IR)^2+(IX_c)^2}=I\sqrt{R^2+X_c^2}=IZ$$

Other equations derived from this relationship are

$$I=\frac{E}{Z}$$

$$\text{Power factor}=\cos\theta=\frac{E_RI}{EI}=\frac{R}{Z}$$

SERIES CIRCUITS WITH INDUCTANCE, CAPACITANCE, AND RESISTANCE

When series circuits contain both capacitance and inductance, the effect of capacitive reactance is directly opposed to that of inductive reactance. The total reactance of a circuit is therefore the difference between the inductive reactance and the capacitive reactance which is expressed in equations for series circuits as follows:

$$E=I\sqrt{R^2+(X_L-X_c)^2}$$

$$\text{Cos }\theta=\frac{R}{\sqrt{R^2+(X_L-X_c)^2}}=\frac{R}{Z}$$

THREE-PHASE CIRCUITS

Three-phase power has been adopted by the Navy as standard for all combat ships with alternating-current plants. The polyphase system delivers power which is less fluctuating than the single-phase system. Furthermore, the sizes of polyphase motors and generators in the significant ratings are smaller than corresponding single-phase machines. The three-phase system has been selected as standard, since it has the least number of conductors of any symmetrical polyphase system. These factors contribute toward savings in weight and space, which is an important consideration in ship construction.

In the three-phase system alternators are wound so that they generate three voltages which are 120 electrical degrees apart. The armature windings are connected either *wye* or *delta*, as shown in figure 10.

The following relations exist between phase voltages, line voltages, phase currents, and line currents in these two connections:

Y = connection

1. Line voltages $=\sqrt{3}$ phase voltage, or
   $E_{AB}=\sqrt{3}\,E_{ao}$
   where E_{AB} = line voltage
   and E_{ao} = alternator phase voltage
2. Line current = phase current

Δ = connection

1. Line voltage = phase voltage
2. Line current $=\sqrt{3}$ phase current, or
   $I_A=\sqrt{3}\,I_{ab}$
   where I_A = line current
   I_{ab} = phase current

The total power developed by a three-phase alternator with balanced load is

$$P=\sqrt{3}\,EI\cos\theta$$

where E = line voltage
I = line current

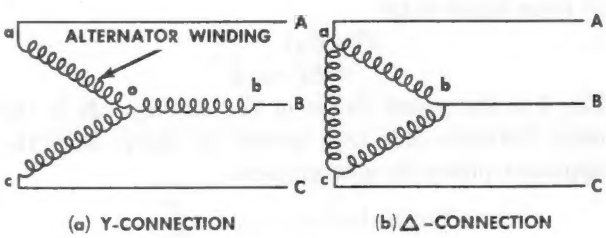


Figure 10.—Three-phase alternator connections.

SOLUTION OF SIMPLE A–C PARALLEL CIRCUIT

If resistance, reactance, and applied voltage in the circuit of figure 11 are known, the branch currents, total current, power factor, and impedance can be calculated by the following procedure:

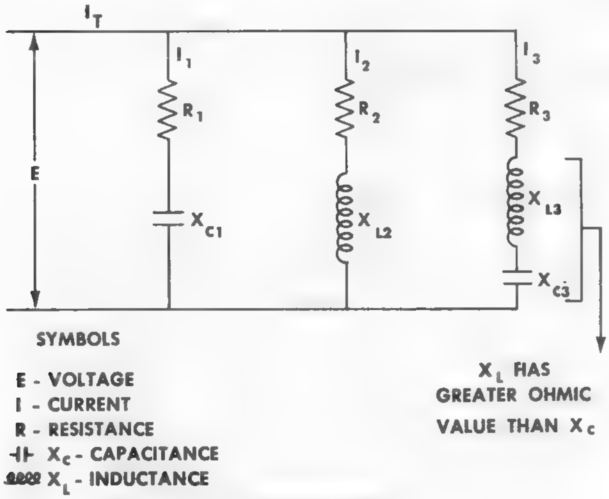


Figure 11.—Parallel circuit (a-c).

$$I_1=\frac{E}{Z_1}=\frac{E}{\sqrt{R_1^2+X_{C1}^2}},\ \tan\theta_1=\frac{X_{C1}}{R_1}$$

$$I_2=\frac{E}{Z_2}=\frac{E}{\sqrt{R_2^2+X_{L2}^2}},\ \tan\theta_2=\frac{X_{L2}}{R_2}$$

$$I_3=\frac{E}{Z_3}=\frac{E}{\sqrt{R_3^2+(X_{L3}-X_{C3})^2}},\ \tan\theta_3=\frac{X_{L3}-X_{C3}}{R_3}$$

The in-phase component of total current I_o is

$$I_o=I_1\cos\theta_1+I_2\cos\theta_2+I_3\cos\theta_3$$

The quadrature component of total current I_q is

$$I_q=-I_1\sin\theta_1+I_2\sin\theta_2+I_3\sin\theta_3$$

The total current I_T is

$$I_T=\sqrt{I_o^2+I_q^2}$$

The power-factor angle can be calculated from

$$\tan\theta=\frac{I_q}{I_o}$$

and power factor $=\cos\theta$

The total impedance is

$$Z=\frac{E}{I_T}$$

CHAPTER 2

POWER DISTRIBUTION SYSTEMS

Capacity and Types of Distribution Systems

The power distribution system is the connecting link between the generators that supply power and the equipment which uses it. In addition to various circuits for transmitting power from one place to another, distribution systems include equipment for protection of generators, cable, distribution equipment, and to some extent the connected load. Power distribution systems are designed to permit removal of faulty or damaged equipment from the system with minimum interruption of power supply to the connected loads.

The design of a power distribution system varies with a vessel's function as a combat unit, as an auxiliary unit to service combat ships, or as a transport for troops and equipment. Important differences exist between those power systems provided for major combat ships, such as battleships, cruisers, aircraft carriers, and destroyers, and those provided for auxiliary vessels, such as landing ships, patrol craft, and fleet supply ships. These differences are principally related to the number and location of main generating plants, the amount and distribution of emergency power, and the kind of power (a-c or d-c, low-voltage or high-voltage) used.

MAIN COMPONENTS OF DISTRIBUTION SYSTEM

The power distribution system of the major combat ships and some auxiliaries are divided into three main components:

1. *Ship's service distribution system*, which includes the main generators, switchboards, distribution panels, and cables furnishing the normal ship's supply of electric power.
2. *Emergency distribution system*, which includes one or more emergency generators and an emergency distribution system to furnish a limited amount of power for the operation of vital loads when there is a failure of the normal power supply.
3. *Casualty power distribution system*, which includes a system of portable cables and connection terminals for making temporary electrical connections if the permanently installed ship's service and emergency distribution systems are damaged.

Generators

SHIP'S SERVICE GENERATORS

The ship's service distribution system receives its power from the ship's service generators, which are driven by steam turbines or Diesel engines, depending, respectively, on whether the propulsion plant is steam or Diesel. Large combat ships have as many as eight turbo-generators distributed throughout the machinery spaces. They can be operated independently or in multiple to serve all parts of the distribution system. This decentralization of generating capacity is carried out to a lesser degree on destroyers and destroyer escorts by dividing the system generating capacity between two generators, one located in the forward engine room and one located in the after engine room.

Most auxiliary vessels have only a single engine

room, and there are many steam propelled vessels on which the engine room and fireroom are combined. Generators on these vessels are usually installed in the same compartment with the propulsion engines.

EMERGENCY GENERATORS

The generators provided for the emergency power distribution system are driven by Diesel engines. Diesel engines are most suitable for this application because of their self-sufficiency and quick-starting ability.

On major combat ships two emergency sets are installed, one forward and one aft, in spaces outside engine rooms and firerooms.

Auxiliary vessels, such as tankers, supply ships, and transports, usually have a single Diesel emergency generator set with its associated switchboard located on the second deck. This is a small capacity plant, which is designed to furnish only an emergency power supply to emergency lighting, vital interior communication, radio, and radar.

Emergency generators are not furnished on smaller patrol vessels, landing craft, and tugs. Most of these vessels are Diesel-propelled, and their Diesel-driven generators provide sufficient reliability of power supply to satisfy ordinary requirements commensurate with the size of the vessel, operating conditions, and type of construction.

Application of Alternating Current and Direct Current

A–C DISTRIBUTION

Alternating-current distribution systems have been installed on all major combat ships of the Navy since 1935. Higher voltages permissible with alternating current and the simplified construction of a-c motors, generators, and controls have resulted in a considerable saving in weight and space in the larger electrical installations. The a-c system is also preferable to the d-c system because of easier maintenance and lower cost.

Alternating-current motors are essentially constant-speed motors, which are generally not directly adaptable for applications requiring a wide range of speed control, such as winches, windlasses, and steering gear. For this reason, alternating current was not adopted by the Navy until comparatively recent years.

With the increase in the size of electric plants on naval vessels, the loads requiring variable-speed drive became a smaller proportion of the total load. It became practical therefore to utilize the a-c system as a major source of electric power aboard combat ships. The inherently constant-speed a-c motor was adapted to the few auxiliaries requiring variable-speed drive by interposing hydraulic variable-speed drive between motors and auxiliaries. This type of drive utilizes a variable-stroke pump in conjunction with a constant-stroke pump for making speed changes over a wide range when driven by a constant-speed prime mover.

D–C SYSTEMS

On large auxiliary vessels where cargo winches or other hoists are a large proportion of the load, the hydraulic drive is impractical because of its increased weight, size, and cost, as compared with similar d-c equipment. Direct-current systems are, therefore, found aboard the vast fleet of large naval auxiliaries including supply ships, ammunition ships, and transports.

When the total generating capacity of a ship does not exceed 60 kilowatts, the use of d-c generators represents a saving in weight, as compared with three-phase a-c machines. Furthermore, on small ships the need for voltage regulators, synchronizing devices, and a large switchboard with the a-c system presents certain disadvantages which the d-c system does not have.

Auxiliary A–C and D–C Supply

On vessels with a-c systems a limited amount of d-c power is required to operate the degaussing system, searchlights, and certain interior-communication equipment. Similarly, radio, radar, fire-control, and IC equipment on ships with d-c systems require a small amount of a-c power. The most common means of conversion from alternating current to direct current, or vice versa, is with motor generator sets.

A–C System Voltage, Phase, and Frequency

The majority of a-c distribution systems on ships of the United States Navy are 450 volts, three-phase, 60-cycle, three-wire systems. Lighting systems are 117-volt three-phase, 60-cycle, three-wire distribution systems supplied from the power circuits through transformer banks. All systems are ungrounded.

D–C System Voltage

There are three general classifications of d-c power voltages aboard naval vessels, the choice of any one depending on the size of the vessel and the proportion of power load to lighting load. In general the applications are as follows:

1. Low-voltage systems, 12-volt or 24-volt, for motor torpedo boats, small landing craft, and small boats.
2. Two-wire, 120-volt systems for medium size vessels on which the electrical load is small or on which the lighting and small motor load is a major part of the total connected load.
3. Three-wire, 120/240-volt systems on all large vessels.

Three-wire systems takes full advantage of the use of lighter and more standard 240-volt rotating equipment while providing a 120-volt system for lighting and other low-voltage loads. Generators are three-wire sets providing positive, negative, and neutral leads for connection to the distribution switchboard and panels. Distribution to power loads is two-wire, 240-volts, whereas three-wire 120/240-volt distribution is made to panels which feed the 120-volt lighting system. Distribution to lighting loads is two-wire, 120-volt, but the cable conductors are connected at the panels so that the load is approximately balanced on the positive and negative sides of the line.

Power Distribution System Equipment

INTRODUCTION

The power distribution system includes as its basic components, ship's service generator and distribution switchboards or switchgear groups, switchboards, power-distribution panels, bus-transfer equipment, and interconnecting cable to individual power loads, and other systems.

SHIP'S SERVICE SWITCHBOARDS OR SWITCHGEAR GROUPS

The equipment of a ship's service switchboard is mounted on, or behind, a series of panels which are combined into a single assembly. The assembly is supported by a sturdy box framework built of steel angles and other structural shapes. This is the general type of construction found on most ships of the Navy.

Switchgear groups have, however, replaced the conventional type of ship's service switchboard on the later types of major combat vessels. A switchgear group is essentially the same as a switchboard except that instead of being a single structure, it consists of two or more individual sections connected by cables but separated sufficiently to localize damage from fire or fault.

The equipment of a switchboard or switchgear group includes all circuit breakers, switches, meters, and control and indicating devices necessary for the switching, protection, and control of generators and distribution circuits.

Emergency Switchboards

Emergency switchboards are used for control of emergency generators and for distribution of emergency power to certain vital loads.

The loads connected to the emergency switchboard normally receive power from the ship's service power system through a connecting feeder from a ship's service switchboard. On large combat ships, each emergency switchboard is served with two feeders from two different ship's service switchboards, one of which is the preferred source of normal power and the other, the alternate source.

The equipment of emergency switchboards on combat ships and on some auxiliary ships includes automatic control for starting the Diesel generator and an automatically operated bus-transfer unit to shift the load to the emergency generator supply when there is a failure in power supply from ship's service feeders. On ships with both normal and alternate feeders, an additional bus-transfer unit serves to transfer the load from the normal source to the alternate source, when the normal power fails. Under these conditions the Diesel generator

will not start and the emergency bus-transfer unit will not operate unless the alternate source of power also fails.

BUS-TRANSFER EQUIPMENT

Equipment which serves to transfer loads from normal to alternate feeders or from the ship's service supply to emergency supply is known as *bus-transfer equipment*. In addition to its application on the emergency switchboard, it is installed in other parts of distribution systems on combat ships.

Bus-transfer equipment may be either *automatic* or *manual*. Automatic operation is used on other applications besides the emergency switchboard as follows:

1. On emergency lighting circuits to transfer from ship's service supply to emergency supply.
2. On the steering-power switchboard to transfer from ship's service supply to emergency supply.
3. On the power supply to control motors for hangar and turret sprinkling systems to transfer from ship's service supply to emergency supply.

POWER DISTRIBUTION PANELS

On ships with relatively small power distribution systems all power loads are fed largely from the distribution section of ship's service or emergency switchboards. On ships with fairly large distribution systems, however, a single feeder from a switchboard may be subdivided into several mains and submains (see paragraph on "Circuit Identification") by power distribution panels, before actually being connected to its entire load.

Power distribution panels are mounted in sheet-metal enclosures and include an assembly of the necessary fused switches or circuit breakers, connecting bus and terminals for subdividing an incoming circuit into several branch circuits. Each fused switch or circuit breaker is of sufficient rating to carry the continuous-load current of its respective branch circuit and to interrupt that circuit under fault conditions.

Cable

Electric cables constitute the major part of any ship's electrical distribution system. There are many different types installed to suit the varying conditions of heat, cold, dryness, dampness, vibration, flexibility, and shock found on naval vessels. The principal types will be described in some detail in chapter 11.

Choice of cable size for power circuits depends on the current requirements of loads connected to the cable and the allowable voltage drop in the section of cable being considered. The current-carrying capacity is governed by the ability of the cable to carry continuously a certain magnitude of current without excessive rise of temperature. This is usually the determining factor in the choice of cable since the comparatively short runs of cable in shipboard installation usually keep the voltage drop within allowable limits when the cable has sufficient current-carrying capacity.

Damage to cable caused by collision or engagement in battle can disrupt the circuits of a distribution system so that generators, switchboards, and other equipment cannot carry out their functions even though they themselves remain intact and in good operating condition. Therefore, naval distribution systems are equipped with normal and alternate feeders to vital auxiliaries and bus ties between switchboards. Main cable runs are located within the armored envelope of the ship when such protection is practical, and cable to guns and gun directors is protected by installation in armored tubes.

Interconnection of Power Distribution Equipment and Loads

SHIP'S SERVICE GENERATORS AND SWITCHGEAR

An important factor contributing to the reliability of a ship's service electric plant on combat ships is the location in different parts of the ship of two or more independently operated generating plants with associated switchgear. This diversity in power supply reduces the vulnerability of the electric plant to the effects of battle damage, particularly where damage is concentrated at one location on the ship.

On smaller combat ships, such as destroyers and destroyer escorts, this scheme of power distribution is carried out with an installation that includes a generating plant with associated switchgear in the

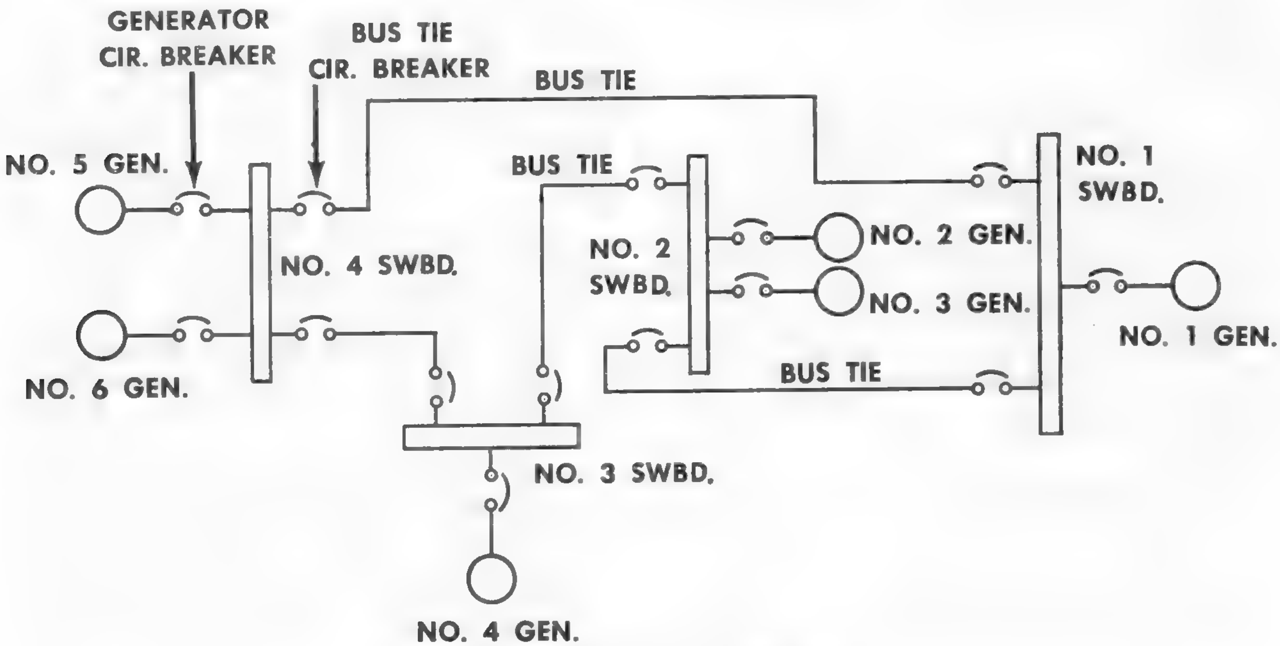


Figure 12.—Bus ties on large combat ship.

forward engine room and similar equipment in the after engine room. The greatest reliability is attained when each plant is operating independently to serve its load. This is known as *split-plant operation*. A bus tie, however, is provided between the respective switchgear for the purpose of interconnection when it is required that a single generator serve the entire ship's load.

Battleships, aircraft carriers, and cruisers generally have four ship's service switchboards or switchgear groups with associated generator or generators located in different machinery spaces throughout the ship. Here again the greatest reliability is to be realized with all generating plants operating independently, and this is established practice when the ship is operating under alerted or actual combat conditions with its generating plant undamaged.

Bus ties arranged as illustrated in figure 12 provide interconnections between switchboards for paralleling generating plants or for serving any one switchboard with power from the generator or generators of a remote switchboard.

Some of the typical methods of interconnecting switchboards or switchgear groups under various operating conditions at sea and in port are outlined as follows:

1. At sea, normal cruising, condition x-ray:
   a. No. 1 and No. 2 generators supplying entire ship's load. Bus-tie breakers closed between No. 1 and No. 4 switchboards and No. 2 and No. 3 switchboards.
   b. No. 1 and No. 4 generators supplying entire ship's load. Bus-tie breakers closed between No. 1 and No. 2 switchboards and between No. 3 and No. 4 switchboards.
2. In port:
   a. Single generator or two generators on the same switchboard supplying entire ship's load. All bus ties closed.
   b. Two generators on two different switchboards supplying entire ship's load. Bus ties closed similar to a and b under 1.
3. Battle—condition zebra:
   a. All generators operating and connected to their respective switchboards. All bus-tie circuit breakers open with generating plants operating independently. This is called *split-plant operation* and is the normal setup for operation when engaged in combat or cruising in waters where the ship is subject to attack.

b. Loss of generator No. 1. Bus tie closed between switchboard No. 1 and switchboard No. 2.

c. Loss of switchboard No. 1. All bus ties remain open. Vital loads served by alternate feeders from other switchboards.

d. No. 1 and No. 2 generators lost. Bus ties closed between No. 1 and No. 4 switchboards and between No. 2 and No. 3 switchboards.

e. Other possible conditions are treated in a similar manner with bus ties open wherever possible to preserve the maximum amount of segregation between generating plants.

VITAL AND NONVITAL LOADS

The loads of a distribution system are classified as *vital* or *nonvital*, according to the reliability required of the service. Vital loads include all electrical auxiliaries or systems which are considered the most essential to the military effectiveness of the vessel. Nonvital loads include those auxiliaries and systems not particularly related to the military effectiveness of the vessel.

Two and sometimes three independent sources of power are provided for selected vital loads. The following combinations of feeders may serve a load, depending on its magnitude and importance:

1. Normal and alternate ship's service feeders.
2. Normal ship's service feeder and emergency feeder.
3. Normal, alternate, and emergency feeders.

In the design of distribution systems the connection of large vital loads to the emergency supply is regulated by practical considerations as to the size of emergency generators to be installed. The extent to which those combinations are provided is tabulated below:

EMERGENCY SWITCHBOARD BUS FEEDERS

On vessels with a single ship's service switchboard and a single emergency switchboard, the emergency switchboard is normally energized by a single bus feeder from the main switchboard. The term *bus feeder* in this instance is not to be confused with bus tie since the latter implies parallel operation between two or more generators remotely located from each other. The emergency generator is never intended for operation in parallel with the main ship's service generators or with another emergency generator.

On combat ships where there are generally two or more ship's service switchboards and two emergency switchboards, bus feeders are provided as follows:

1. Normal and alternate feeders from two ship's service switchboards.
2. Remote emergency bus feeders between forward and after emergency switchboards. The remote emergency bus is a small distribution

TABLE I.—*Tabulation of normal, alternate, and emergency feeders.*

Load	Normal	Alternate	Emergency
Steering (1 steering gear)	X	X	X
Steering (2 steering gears)	X	--------	X
Main battery gun mounts and directors	X	X	X
Secondary battery gun mounts and directors	X	--------	X
Interior-communication and fire-control switchboards	X	X	X
Turrets	X	X	--------
Main battery directors (single purpose)	X	--------	X
Pumps, auxiliary circulating*	X	--------	X
Pumps, auxiliary condensate*	X	--------	X
Pumps, main fuel oil service*	X	--------	X
Pumps, lubricating oil*	X	--------	X
Forced draft blowers	X	--------	X
Lighting (emergency)	X	X	X
Radio (emergency)	X	--------	X
Radio (central)	X	--------	X
Radio transmitters	X	--------	X
Radar and RCM equipment**	X	--------	X
Radio amplifier-speakers and radio receivers in CIC	X	--------	X
Sonar**	X	--------	X
Hangar and turret sprinkling valve control	X	--------	X
Engine-room ventilation	X	--------	X
Fireroom ventilation (BB's, CV's, and CL's)	X	--------	X
Pumps (emergency submersible steering)	X	--------	X
Pumps, fire	X	--------	X

*If pumps are stand-bys, only a normal feeder is provided.

**In general fire-control, radar, and fire-control sonar equipments are energized from the IC switchboards and panels supplying the associated fire-control circuits.

section on each emergency switchboard, which is segregated from the main distribution bus. It is used to supply certain select vital loads with power from the remote emergency switchboard when power is not available either from the ship's service bus feeders or from the local emergency generator. Each emergency switchboard is provided with a remote emergency bus feeder from the remote emergency switchboard.

3. Emergency feedback between emergency switchboards and ship's service switchboards. The emergency feedback makes it possible to operate a selected portion of the ship's service switchboard load by emergency power. This feature facilitates starting up the machinery after major steam alteration and repairs, and provides for operation of necessary auxiliaries and lighting during a period of repairs away from shore based power.

   Feedback is generally through a normal or alternate ship's service switchboard feeder with a special feedback switch or circuit breaker on the emergency switchboard arranged to bypass the bus-transfer contactors.

POWER OUTLETS

Combat ships are provided with multipurpose power outlets energized at 450 volts, three-phase, for repair, maintenance, and damage control equipment, including submersible pumps, portable welding sets, and portable hoists.

These outlets are fed from power distribution panels with a minimum number connected to any one panel in order to provide the maximum diversity in supply. They are so located that two portable pumps can be operated in any compartment by the use of 75 feet of cable per pump, except on some of the larger ships, which may require 150 feet of cable per pump. The use of 75-foot extension cables with portable receptacle triple outlet boxes makes it possible to operate six portable pumps in any watertight compartment. An adapter is provided with the 75-foot extension cables for making connections to the casualty power system if power is not available at the outlets.

A considerable number of 115-volt, single-phase outlets fed from lighting panels are distributed throughout a combat ship for operation of small electrical tools.

Auxiliary vessels with d-c distribution are fitted out with 250-volt and 125-volt outlets for damage control and repair equipment.

All outlets with the exception of convenience outlets in living quarters are of the grounded type to prevent the occurrence of dangerous potentials between tool housings and the ship's structure. The grounding feature is built into the outlet and plug assemblies.

CIRCUIT IDENTIFICATION

All power distribution cables are marked by means of cable tags to insure that they may be readily identified as to their source, relative importance, and classification for purposes of maintenance and replacement. These circuits are designated as follows:

1. Classification:
   a. F—General power feeders.
      General power circuits supply power to motors and appliances which are not essential during battle and are therefore nonvital.
   b. FB—Battle power feeders.
      These circuits supply power to those auxiliaries and other systems which operate under battle conditions.
   c. XFE—Emergency power feeders.
2. Source:
   The connecting cable for distribution of electric power to various parts of a ship includes feeders, mains, submains, branches, and subbranches.
   a. A feeder is a cable connected to a distribution switchboard or to a load center panel located in the same room as a switchboard or switchgear group. This identification is further subdivided into two classes; namely, "regular" feeders representing those cables used for supplying power to auxiliaries of the vessels and "zero" feeders which interconnect switchboards, generators to switchboard, shore connections, and the like.
   b. A main is a cable connected to a feeder.
   c. A submain is connected to a main.
   d. A branch is connected to a submain and a sub-branch to a branch.

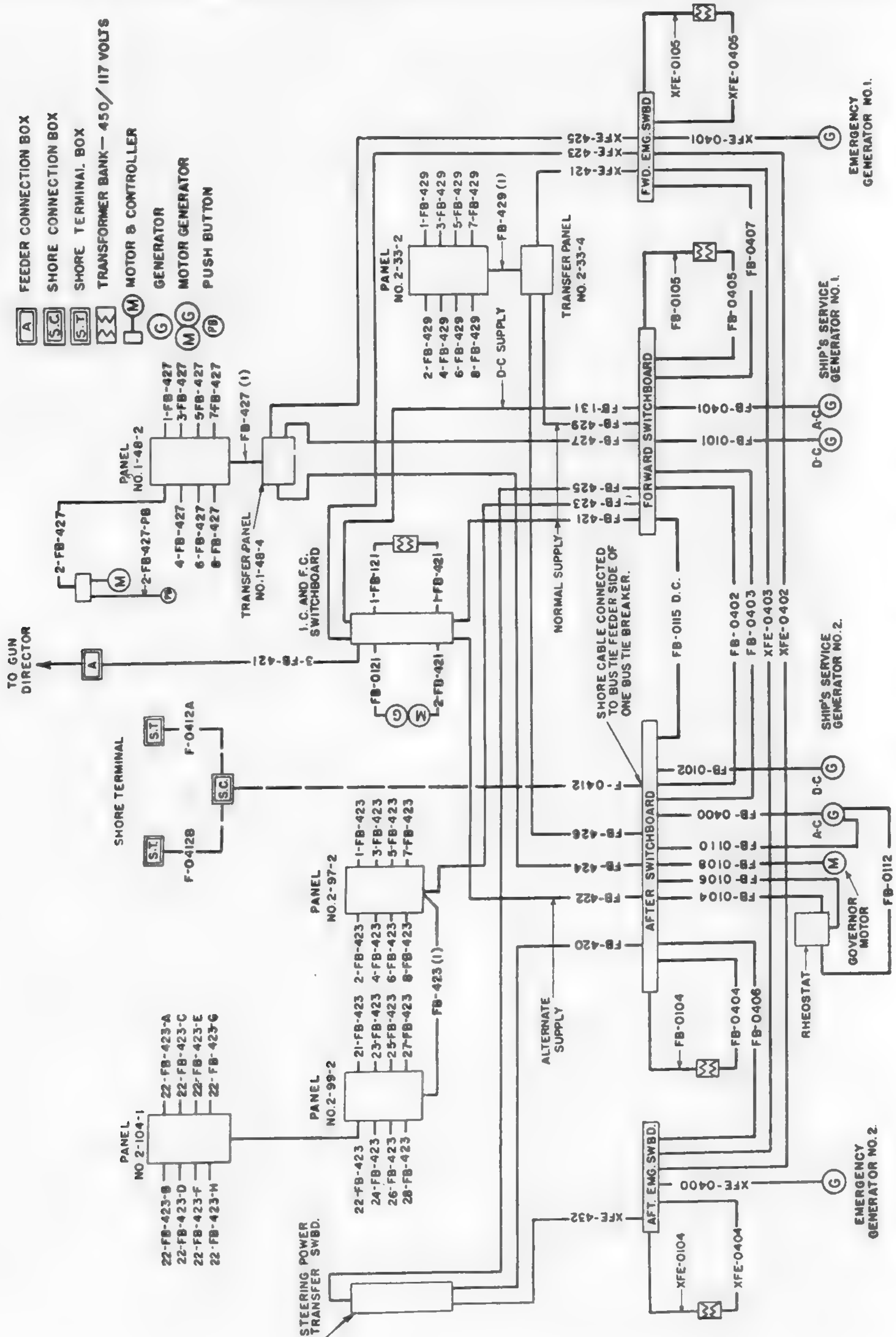


Figure 13.—Cable markings in power distribution system.

3. Cable markings:
   a. A feeder is designated by letters (F, FB, XFE) as applicable, followed by a dash and a number, for example, FB-411. Feeders connected to forward switchboards are given odd numbers and feeders connected to after switchboards are given even numbers.

      Feeders of 450 volts are numbered in the 400 to 999 series, and those of 117 volts are numbered in the 100 to 199 series.

      The numbers of interconnecting feeders for switchboards, generators, and similar equipment are prefixed by the cipher "0", as FB-0411.
   b. Mains carry the number of the feeder to which they are connected and are prefixed by numbers from 1 consecutively upward, as 1-FB-420.
   c. Submains carry the number of the main to which they are connected followed by a letter, as 1-FB-410A.
   d. Branches carry the number of the submain followed by numbers from 1 consecutively upward, as 2-FB-403A1. Sub-branches are designated by the branch number followed by a letter, as 2-FB-403A1A.

This system of cable marking is illustrated in figure 13.

The identification tags of all power and lighting cables except branches and sub-branches are colored to indicate whether a cable is vital, semivital or nonvital, as follows:

Vital	Red
Semivital	Yellow
Nonvital	Gray

SHORE POWER CONNECTION

In order to provide power to the ship's distribution system when the ship's generating plant is secured while the ship is in dock or alongside a tender, provision is made to energize the distribution system from dock or tender power. This provision consists of shore connection boxes, which are generally located on the port and starboard sides of the ship on the main deck. The shore connection boxes are connected to one or more of the ship's service switchboards. Shore power requirements are generally confined to lighting and those facilities associated with the living comfort of those on board.

Motor Loads

Motor loads are connected to switchboards, load center panels, or distribution panels, depending on their location with respect to this equipment and also their importance in the classification of vital and nonvital loads. The greatest reliability is from the feeder emanating directly from the switchboard since it is relatively well protected from interruptions in service caused by other loads or by short-circuits on the feeders serving other loads. Next in the order of reliability in supply is the load center panel on large ships and the ordinary distribution panel on smaller ships.

Motors are connected to their source of supply through their respective starters or controllers, which are either manually or magnetically operated. This equipment controls the operation of the motor and protects it from the damaging effects of sustained overloads. It is discussed in considerable detail in chapter 9.

Casualty power connections

The casualty power system is not intended to supply circuits to all the electrical equipment on a vessel but is limited to those facilities necessary to keep the ship afloat and get it out of a danger area and to a limited amount of armament for protection of the ship while in a damaged condition.

A casualty power system includes portable cables, bulkhead terminals, risers, switchboard terminals, and portable switches. On some large combat ships small Diesel engine-driven generator sets were formerly provided as casualty power generators. These were located at points where they would be least likely to be damaged by the same casualty which might damage other generators. Casualty power generators, however, have been eliminated from most of the ships operating today.

Terminals between decks are connected by permanent cable, called risers. Bulkhead terminals usually consist of a single fitting having a set of terminals on either side. This permits the distribution of power between decks and through bulkheads without disturbing watertight integrity.

Casualty power circuit breakers are installed at switchboards so that the terminals can be deenergized when making or breaking system connections. Portable switches are stowed in repair party lockers and can be used when necessary for connecting and disconnecting circuits.

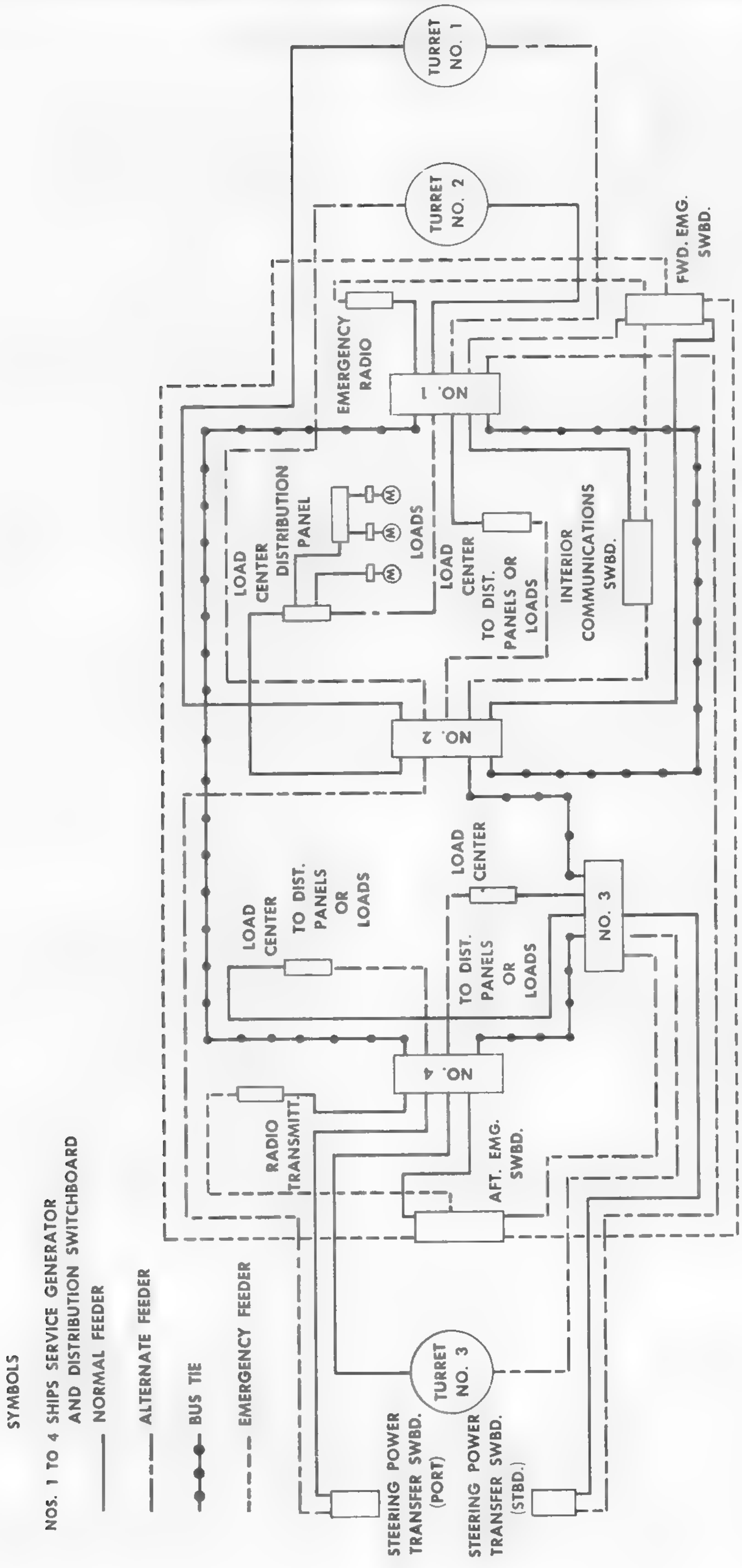


Figure 14.—Battleship power distribution system (schematic diagram).

Typical Distribution Systems

BATTLESHIP

Figure 14, a schematic diagram of a modern battleship's distribution system, illustrates practically all the features of a distribution system discussed in the previous sections.

Analysis of this system will bring out the points listed below, which summarize the previous discussions.

1. Ship's service generator and distribution switchboards can be interconnected to meet various operating conditions by closing bus-tie circuit breakers.
2. Emergency switchboards are normally fed by ship's service switchboards.
3. Emergency switchboards can be interconnected through remote bus feeders for the purpose of supplying both switchboards from one emergency generator. Emergency generators are never paralleled.
4. Certain select vital loads are connected directly to a ship's service switchboard or emergency switchboard instead of distribution panels.
5. Vital loads are connected to two or three sources of supply, depending on their magnitude and importance to the fighting effectiveness of the ship.
6. A single feeder from a switchboard may be subdivided into several mains and submains by power distribution panels before actually being connected to its load.

DESTROYER

The schematic diagram in figure 15 illustrates certain specific features of the distribution system of a modern type destroyer, as follows:

1. Five-inch mounts are served by normal, alternate, and emergency feeders through manual transfer switches.
2. A single steering gear is served by normal, alternate, and emergency feeders.

AUXILIARY SUPPLY SHIP

A typical distribution system for an auxiliary supply ship is illustrated in figure 16.

A great number of the auxiliary ships of the Navy in the last war were originally built as commercial vessels and then converted for naval service. The electrical systems on auxiliary vessels were, therefore, originally designed to comply with regulations for commercial vessels as prescribed by the American Bureau of Shipping and the Bureau of Marine Inspection of the United States Coast Guard.

On ships of this type the system of cable markings follows the commercial system. Main power cables are designated by P, emergency power cables by EP, lighting by L, and interior communication by IC. Feeders are numbered from 1 consecutively upward. Mains, submains, and the like, are numbered in a system similar to the Navy system.

Other significant points of this auxiliary ship's distribution systems are

1. An emergency lighting system independent of the general lighting system is energized directly from the emergency switchboard.
2. A feedback connection is provided from the emergency generator to the main switchboard for dead ship starting.
3. Circuit breakers on feeders to ventilation panels are equipped with shunt trips for interruption of circuits from a remote station.
4. All bus transfers are manually operated.

Protective Devices

GENERAL

The major protective devices, used in a ship's power system include circuit breakers, fused switches, reverse power relays, and overload relays. Descriptions of their construction, operation and maintenance are given in later chapters devoted to the equipment of which they are component parts. (See chapters 6 and 9).

Protective devices fall into three general classifications, as follows:

1. Those whose function is to automatically remove a fault from the system, such as circuit breakers and fused switches.

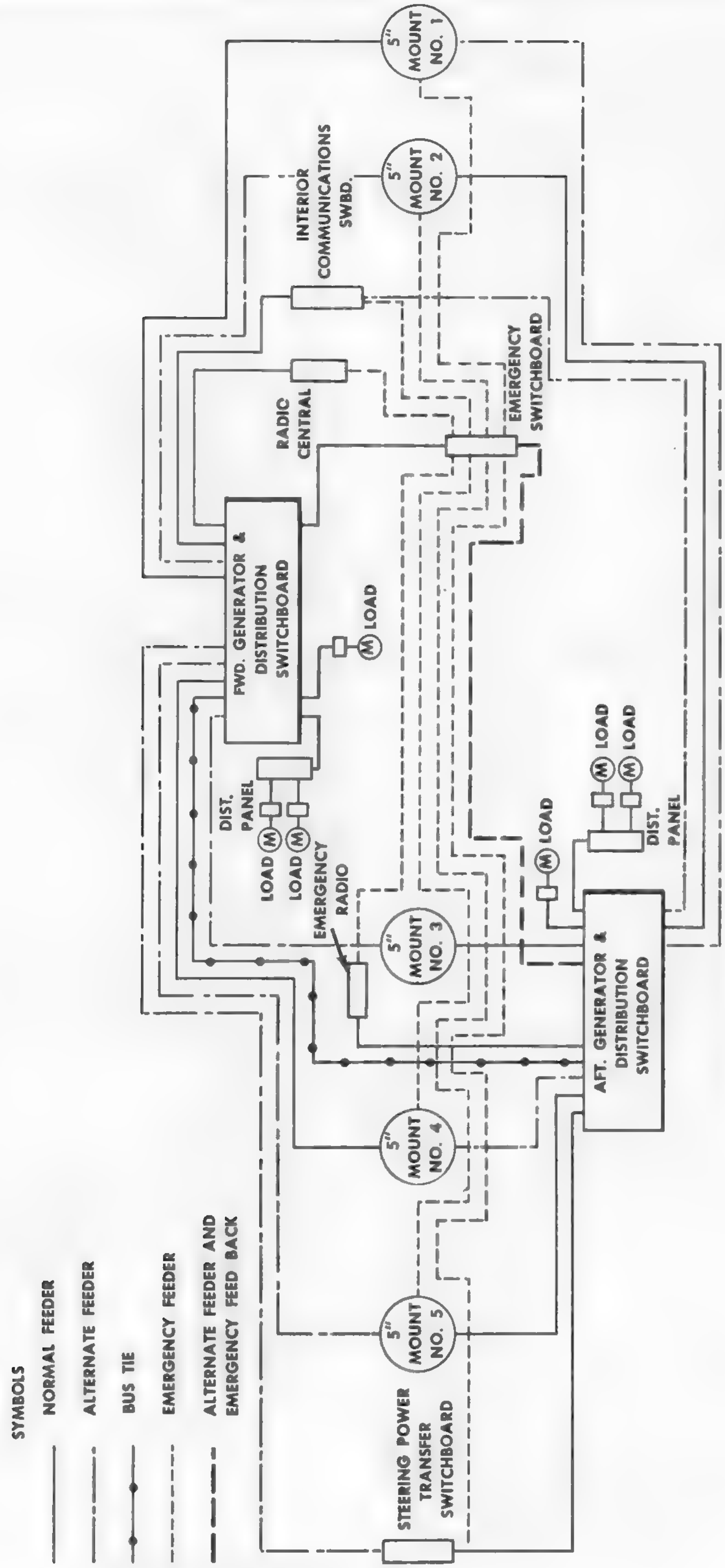


Figure 15.—Destroyer power distribution system (schematic diagram).

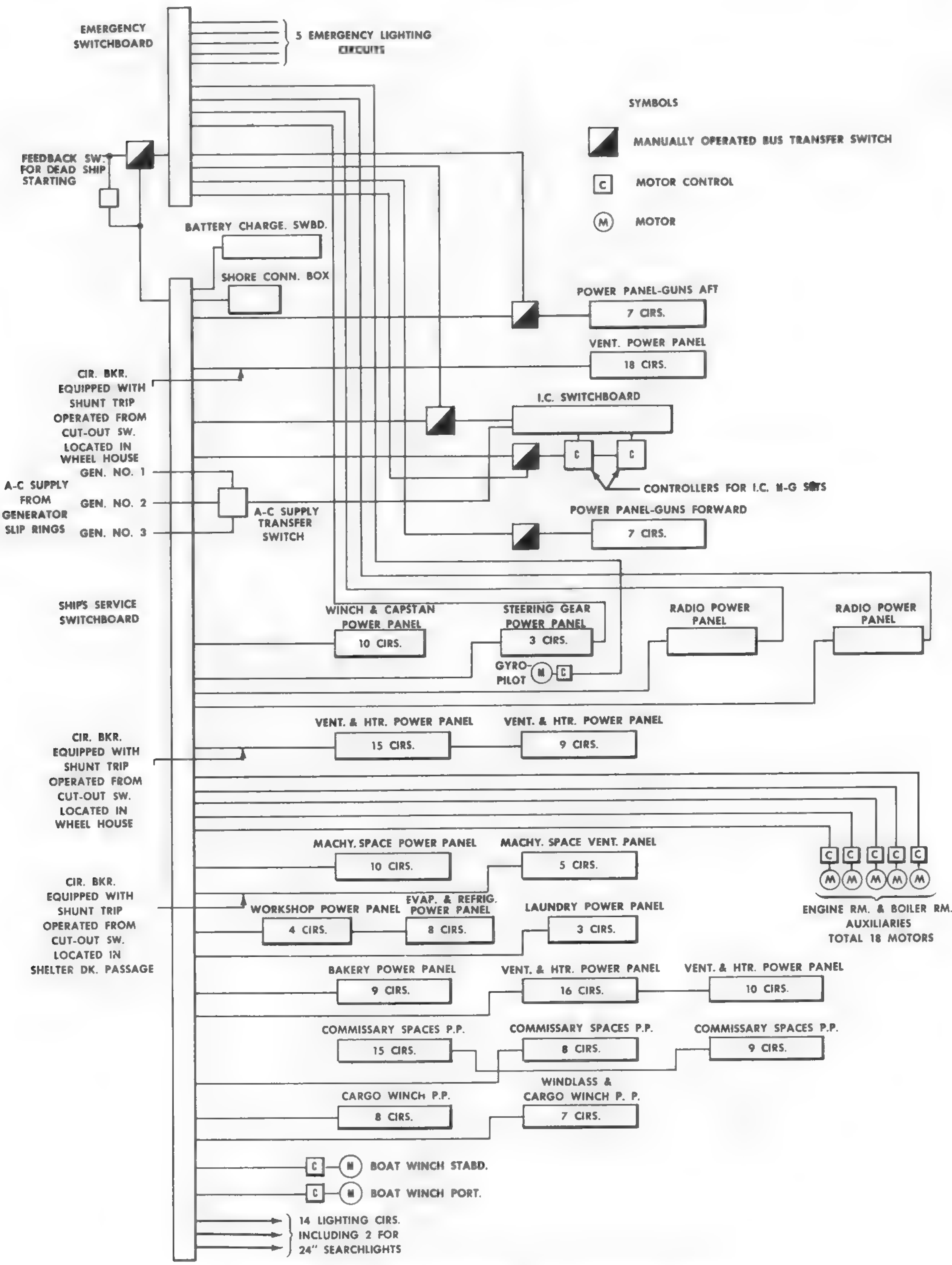


Figure 16.—AKA power distribution system (schematic diagram).

2. Those whose function is to keep a prime mover from being driven by its generator in the event of prime mover failure, such as reverse power relays.

3. Those whose function is to prevent excessive rise of temperature in apparatus due to overloads, such as the overload relays of motor starters.

Fault Protection

A fault is any defect in the distribution system which imposes a short-circuiting effect on cables and equipment and causes a flow of current from the supply to the point of fault in excess of that drawn by the connected load. Faults are of varying intensity and are dependent on the voltage and capacity of the system and the impedance of the fault.

High-speed operation of circuit protective devices is essential, particularly on all low-impedance faults, in order to minimize the damage to cable and apparatus with currents of large magnitude. Some idea of the magnitude of low-impedance faults may be obtained by comparison of the constant current-carrying capacity of certain circuit breakers with their interrupting capacity. A few typical examples are listed below:

Maximum Continuous Current Rating	*Interrupting Capacity*
250 amperes	20,000 amperes a-c 500 volts 15,000 amperes d-c 250 volts
640 amperes	40,000 amperes a-c 500 volts 25,000 amperes d-c 250 volts
1,600 amperes	60,000 amperes a-c 500 volts 50,000 amperes d-c 250 volts

Fault protection in a distribution system is coordinated to provide automatic isolation of a fault with minimum damage and with minimum disturbance to the distribution system. This is accomplished in the design of modern circuit breakers by providing instantaneous tripping for currents of certain magnitudes and inverse time delay for currents under the instantaneous tripping values. Inverse time delay is the intentional delay in the tripping of a circuit breaker. This delay increases with the decrease in magnitude of current. Thus, in a well coordinated system when a fault occurs, it will be isolated by the opening of the circuit breaker in that particular circuit without interruption of power in any of the preceding supply circuits.

The speed at which a circuit breaker is capable of opening a faulted circuit where the current magnitude is in the instantaneous zone is approximately one cycle to three cycles, depending on the circuit-breaker rating.

While circuit breakers have replaced fuses for distribution on switchboards and large panels of combat ships, fuses are still the the most common form of fault protection in branch-circuit protection. Some auxiliary vessels with d-c distribution systems use fused switches almost entirely for fault protection. Time delay with fuses can be incorporated only insofar as fuse characteristics permit. Progressively larger fuse sizes from the load to the power source give some degree of selectivity in fault isolation. The application of fuses is limited to a maximum of 200 amperes. Fuses with higher rating are not used since the time for interrupting low-impedance faults is considered excessive.

Generator Reverse Power Protection

When a generator is operating in parallel with other generators in a system and its prime mover fails, the generator will take power from the system and run as a motor. This may result in damage to the prime mover if the generator is not promptly disconnected.

Generator motoring is prevented by a reverse power relay which operates to trip the generator circuit breaker when the power input to the generator reaches a predetermined value. Settings are made to suit the particular requirement of the installation. Commonly used values of reverse power setting are approximately 5 percent of generator capacity for a-c generators and 10 percent of generator capacity for d-c generators.

Overload Protection

There is no automatic protection of the distribution system against overcurrents slightly in excess of rated capacity. This is entirely a matter of vigilance on the part of operating personnel in detecting slight overload conditions on generators and bus ties from ammeters and wattmeters permanently connected into these circuits. Thus, in the case of a persistent overcurrent, steps can be taken to remedy the condition before it results in damaging effects.

Protection of individual motor loads from sustained overloads is provided by overload relays installed as an integral part of the motor starter or

controller. These relays are of the thermal or magnetic type and operate in conjunction with motor control devices to interrupt the motor power supply when overload currents persist over a safe period of time. Some overload relays are of the instantaneous type, but these are applied only on installations such as windlasses and winches, where instantaneous protection is required to prevent damage to mechanical as well as electrical equipment.

Operation and Maintenance

GENERAL

Proficient operation of power distribution systems is essential for their proper functioning as a reliable source of power under normal and emergency conditions. The emergencies which can arise under battle conditions demand complete familiarity with the equipment installed and a knowledge of how it can be used. A casualty to distribution equipment feeding a vital load demands immediate action to restore power supply through the reserve and emergency facilities provided.

Operating Principles

Certain general operating principles should be used as a guide in training personnel for their duties as power distribution operators aboard ship. These are outlined as follows:

1. Split-plant operation as previously described should be preserved as much as possible in wartime cruising, even under casualty conditions. This can be done to a limited extent by transferring vital loads to alternate feeders when there is a casualty to the generators which ordinarily supply the normal feeders.
2. The current paralleling procedures for a-c or d-c generators should be followed at all times before closing bus ties between switchboards which have their respective generators running and connected.
3. Paralleling of generators is strictly limited to the ship's service system. Ship's service generators are not to be paralleled with emergency generators or shore power, and emergency generators are not to be paralleled with each other or with shore power.
4. When a circuit breaker trips, a certain amount of judgment is required in reclosing it. If it trips after the first reclosing, it may be desirable to investigate the trouble immediately. Further reclosure will depend on how important the restoration of circuit power is. Repeated closures may be necessary, but it should be borne in mind that they may have damaging effects on the circuit breaker and other equipment and must be fully justified as an emergency measure.

   Hold-in devices for circuit breakers should only be used in a rare emergency where damage to electrical equipment is secondary in importance to the continued supply of power for protection of the ship.
5. In transferring the ship's load from the ship's service generators to shore power, care should be exercised to see that all generator circuit breakers are opened before closing the shore power breaker. It also follows that in transferring from shore power to ship's power the shore power circuit breaker should be opened before closing the generator breakers.
6. Emergency Diesel generators can be stopped only from within the space where the Diesel generator is located. Furthermore, as a rule it is necessary to setup the lube-oil alarm manually after the Diesel starts. In some instances, emergency Diesel generators have started because of momentary loss of ship's service voltage at a time when emergency power was not required for the security of the vessel, and when emergency generator spaces were not manned, machines have run for some time before it was realized they were operating unattended. This oversight has often resulted in considerable damage to machinery. Accordingly, on installations not provided with signal systems designed to alert the generator watch stander of conditions in the emergency generator space, precautions should be taken against such a casualty.
7. Switchboard instruments should be read at frequent intervals to reveal overloads, improper division of load between generators

operating in parallel, and other abnormal conditions which require adjustment.

8. The phase sequence of shore power leads should be checked before making connections to the shore-connection box. Ship-phase sequence is ABC for proper rotation of three-phase, motors.

Maintenance

The maintenance of a ship's power distribution system is related to the maintenance of its component parts. General maintenance procedures are discussed in the following chapters on power distribution equipment.

CHAPTER 3

DIRECT-CURRENT GENERATORS

Operating Principles

REVIEW OF GENERATOR FUNDAMENTALS

1. A generator is a machine for converting mechanical energy into electrical energy. This conversion is expressed quantitatively in the equation

$$\text{horsepower} = \frac{\text{kilowatt} \times 10^5}{\text{efficiency} \times 746}$$

where horsepower = Mechanical power input in horsepower
kilowatt = electrical power output in kilowatts
efficiency = percent efficiency

2. The generator works on the principle of electromagnetic induction, with electromotive force being induced by the relative motion of electrical conductors and a magnetic field.

3. The magnitude of electromotive force is proportional to the number of conductors in series in one current path between plus and minus terminals, the strength of the magnetic field, and the speed at which the conductors pass through the magnetic field.

4. When current flows in the windings of a d-c armature, it produces a magnetic field which is at right angles to the main field. The net result is armature reaction, a distortion of the main field flux that causes the generator neutral to advance in the direction of rotation as the load increases. The extent of this neutral shift is sufficient to interfere with proper commutation; this causes excessive sparking at the brushes and damage to both commutator and brushes. Several methods are used to compensate or partially eliminate armature reaction. The use of interpoles is the best known and most commonly used method. Interpoles are installed between the main field poles and have their windings connected in series with the armature circuit. They are designed to neutralize the effects of armature reaction in the vicinity of the geometric neutral at all values of load.

5. As the armature core rotates in the same magnetic field as the armature windings, electromotive forces are also induced in the iron. Since iron is an electrical conductor, currents will circulate within the core; and the result will be *eddy-current losses*. These losses contribute to the over-all losses of the generator. They are kept to a minimum, however, by laminating the core and thereby dividing it into a large number of high resistance paths. In this way the effectiveness of the core as a magnetic circuit is preserved, but the eddy-current loss is reduced.

6. With d-c generators the armature is rotated and the field is stationary. With a-c generators of any appreciable size the field rotates and the conductors are stationary.

D-C Generator Connections

There are three general types of d-c generators in use on naval ships: shunt, stabilized shunt, and compound. These terms relate to the connection of field windings with respect to the armature.

Shunt generator.—With the shunt generator the field circuit is connected across the generator terminals, as shown in figure 17.

A variable resistance, called a rheostat, is usually connected in series with the field for the purpose of varying the field current. Since the field excitation affects the generator voltage, the field rheostat is used to adjust the output voltage.

Shunt field coils are made up of many turns of fine wire, which produce a strong magnetic field of

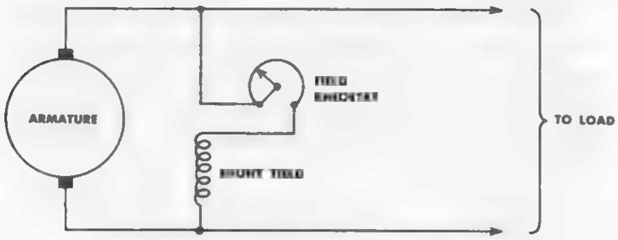


Figure 17.—Connections for shunt generator.

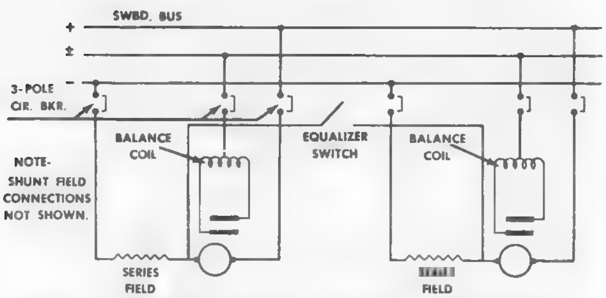


Figure 18.—Parallel connection of compound three-wire generators.

many ampere turns at a comparatively low value of current. All shunt field coils are connected in series with each other and provide alternate north and south poles around the generator frame.

The chief disadvantage of shunt generators is the sizeable drop in voltage between no-load and full-load. This characteristic is brought about by the three factors listed below:

1. Voltage drop in the armature circuit.
2. Weakening of the field owing to armature reaction.
3. Decreased field current owing to the drop in terminal voltage caused by factors 1 and 2.

Stabilized shunt generators.—Generators for ship's service plants are generally equipped with a light series field, wound on the same poles with the shunt field to obtain closer voltage regulation than that normally obtained with plain shunt generators. The series field is connected in series with the armature or load and consists of a few turns of heavy conductor designed to carry the full-load current of the generator. It produces an additional field strength directly proportional to the load and, therefore, partially compensates for the effects of shunt-field weakening and voltage drop. Generators which include a light series field are said to have a stabilized shunt field.

The drop in voltage from no-load to full-load with stabilized shunt machines is sufficient to obtain good parallel operation without employing voltage regulators or equalizers. At the same time these machines provide voltage regulation which is generally within the limits required by naval ships with d-c power.

Compound generators.—Compound generators employ a heavier series field than the stabilized shunt machine and are usually designed to produce the same voltage at full-load as at no-load. This type of design is known as a *flat-compounded generator*. If the adjustment is such that the voltage at full-load is less than the voltage at no-load, the generator is said to be undercompounded.

Compound machines will not operate in parallel and divide the load successfully without the use of equalizers or voltage regulators. The equalizer connection is made at a point where the armature and series-field leads join. It connects the armatures and series fields of two or more generators in parallel and thereby divides the load between generators in proportion to their capacity. A typical equalizer connection is shown in the diagram of figure 18.

To be effective equalizer connections must have resistances which are considerably lower than those of the series fields. Consequently, a very heavy conductor is required, especially if there is a considerable distance between the machines operating in parallel.

The connections for compound generators are shown in figure 19.

If the shunt field is connected directly across the armature, it is said to be connected *short shunt*. When the shunt field is connected outside the series field, it is said to be connected *long shunt*.

Three-Wire Generators

Shipboard generators have three leads for connection to the load. These include a positive, a negative, and a neutral lead, with the neutral at a potential midway between that of positive and negative. The voltage between positive and neu-

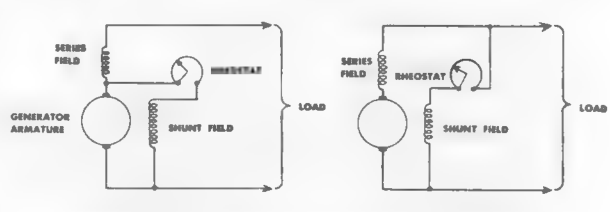


Figure 19.—Compound generator connections.

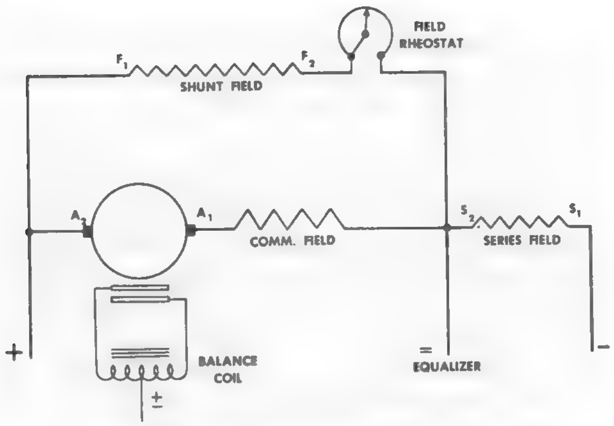


Figure 20.—Three-wire generator connections.

tral or negative and neutral is therefore one-half of that between positive and negative. On a ship's service distribution system, main motor loads are connected between positive and negative whereas lighting, and small motors are connected positive to neutral or negative to neutral. With the latter connections the loads are balanced between the positive and negative sides.

Brushes and two collector rings are employed to connect two diametrically opposed points of the armature to a high-impedance coil. The generator neutral is connected to the midpoint of this balance coil and to the load. These connections are shown in figure 20.

The center of the impedance coil is always midway in potential between the positive and the negative brushes on the commutator, and the connection at that point becomes the generator neutral. The coil is designed to offer a high impedance to alternating current and a low resistance to the flow of direct current. A small amount of alternating current flows in the coil at all times and is of constant value for all loaded conditions.

When there is an unbalanced load on the three-wire system, the difference between positive and negative values of current will flow in the neutral. The neutral, therefore, offers a return circuit for the amount of unbalance through the low resistance of the impedance coil back to the generator armature winding. The magnitude of unbalance allowed with most ship's service three-wire systems is 25 percent of the full-load current.

The coil used with three-wire generators is mounted in a separate enclosure and is installed within convenient distance for connection to generator terminals. It is generally known as a balance coil or auto-transformer.

Parallel Operation

If two d-c generators are connected in parallel, their terminal voltages must be the same.

Shunt generators are particularly adaptable for parallel operation because of their drooping voltage characteristic with an increase in load. Any tendency of one generator to take more than its share of the load results in changes of voltage that oppose this tendency.

The distribution of load between two generators of equal capacity is determined by the field excitations of the two machines, the greater field excitation taking the greater share of load. The operator can control the distribution by varying the settings of field rheostats.

Compound generators cannot be successfully paralleled without the use of equalizers that parallel their series fields. The net effect of this connection is to cause equal excitation of both series fields when one generator tends to take more than its share of the load; this maintains the original distribution of load.

Construction

The essential parts of a d-c generator are the yoke, or frame, the field pieces, the rotating armature, and the brushes.

Magnetic Circuit

The yoke, or frame, serves two purposes. It is a portion of the magnetic circuit, and it acts as a mechanical support for the machine as a whole. It is made of steel plate shaped and welded to form a cylinder.

Field pieces are essential parts of the magnetic circuit. They consist of laminated sheet-steel cores around which are fitted shunt and/or series coils. The simple field magnetic circuit is illustrated by the diagram of figure 21.

Field windings

A shunt field winding is connected across the generator armature or across the generator termi-

nals. It is a coil of many turns of fine wire wound in layers around an insulated spool.

A series field winding is connected in series with the armature circuit and is energized by the load current. It is usually a bare copper strap, wound around the outside of the shunt field and held in place and clear of the shunt field by suitable insulated supports.

Field-winding assemblies are fitted over the field cores, which are in turn bolted to the frame by stud bolts fitted through the frame into tapped holes in the core. The assembled field piece is shown in figure 22.

Commutating Poles

Commutating poles, or interpoles, are connected in series with the armature circuit and are installed midway between the main field poles. Their function is to correct for flux distortion due to armature reaction and permit commutation at all magnitudes of load without excessive sparking at the brushes. A commutating pole usually consists of a heavy insulated conductor wound directly on a laminated core. The assembly is bolted to the yoke, or frame, in the same manner as the main field pieces.

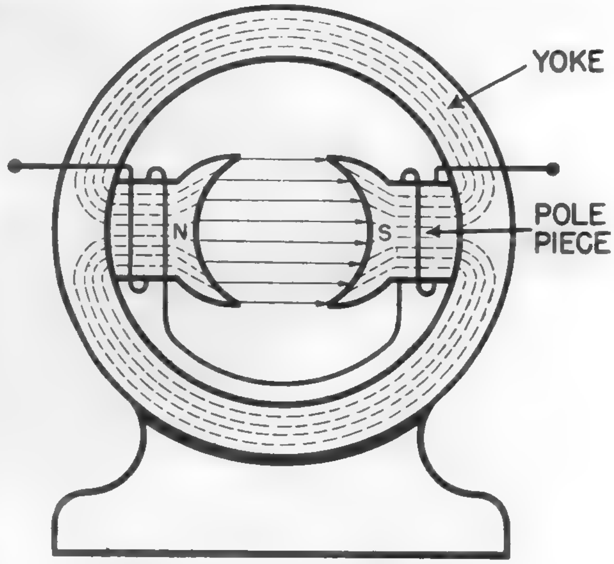
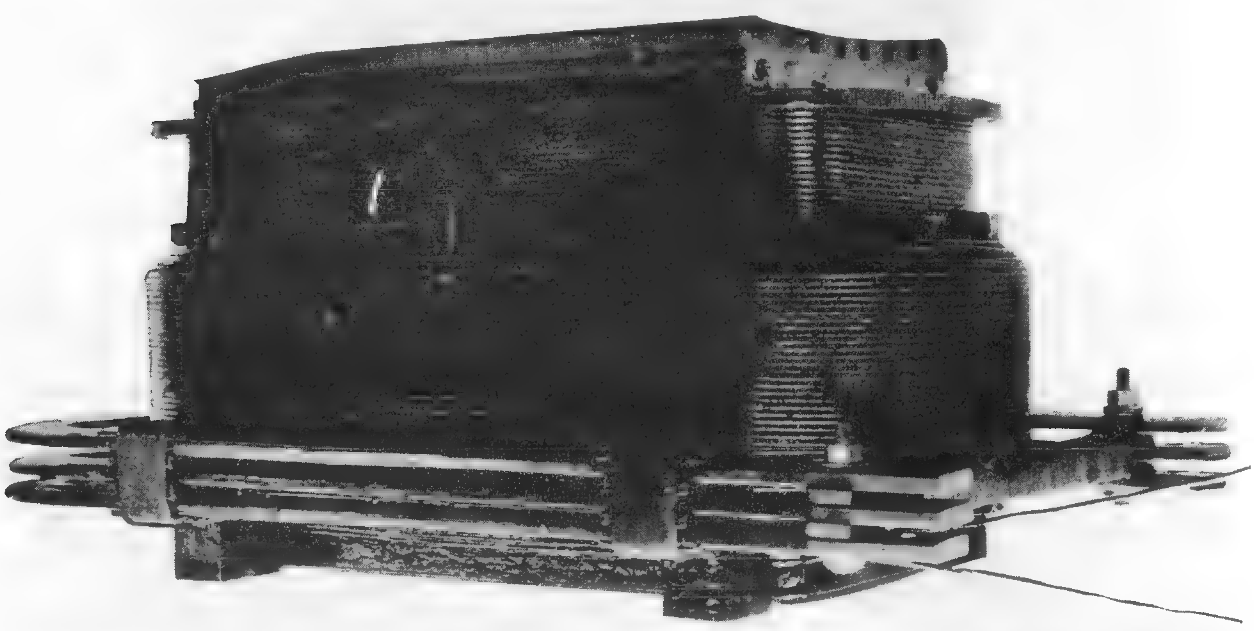


Figure 21.—Generator magnetic field.

Armature and Commutator

The modern drum-wound armature is shown in figure 23.

The armature includes a slotted, laminated iron core, a commutator, and a winding usually made up of interconnected form-wound coils.



Courtesy of Westinghouse Electric Corp.

Figure 22.—Assembled field piece.

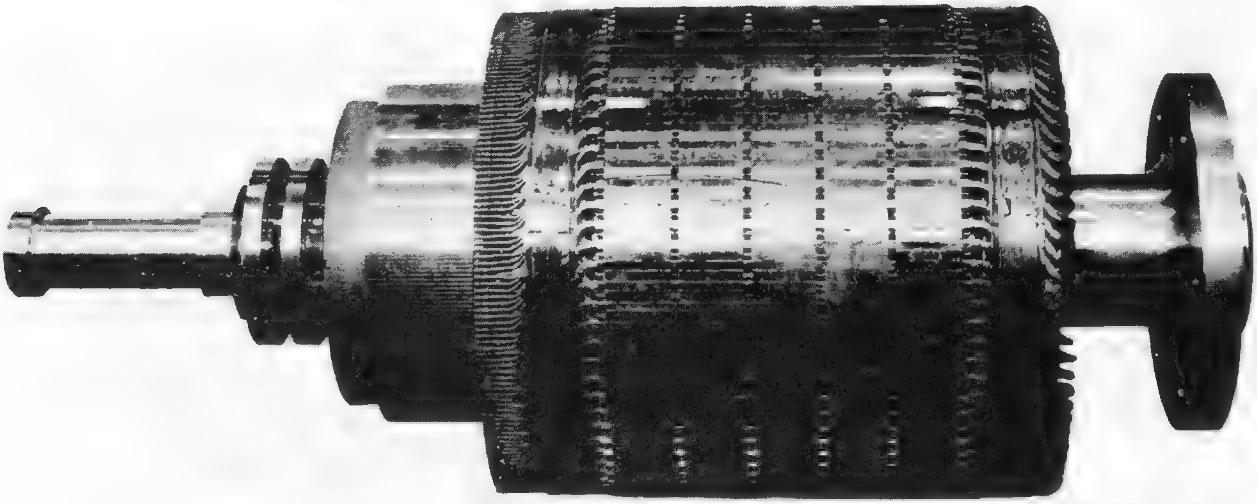


Figure 23.—Generator armature. *Courtesy of General Electric Co.*

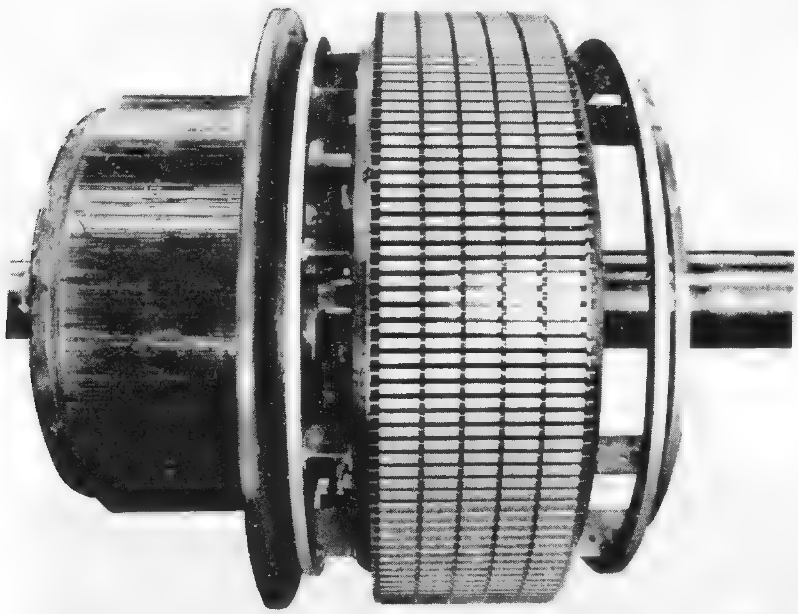


Figure 24.—Armature core. *Courtesy of Westinghouse Electric Corp.*

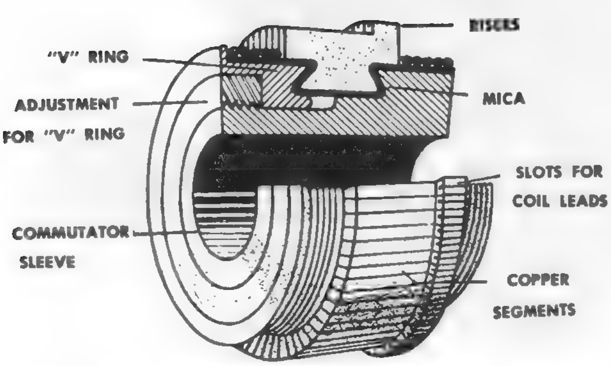
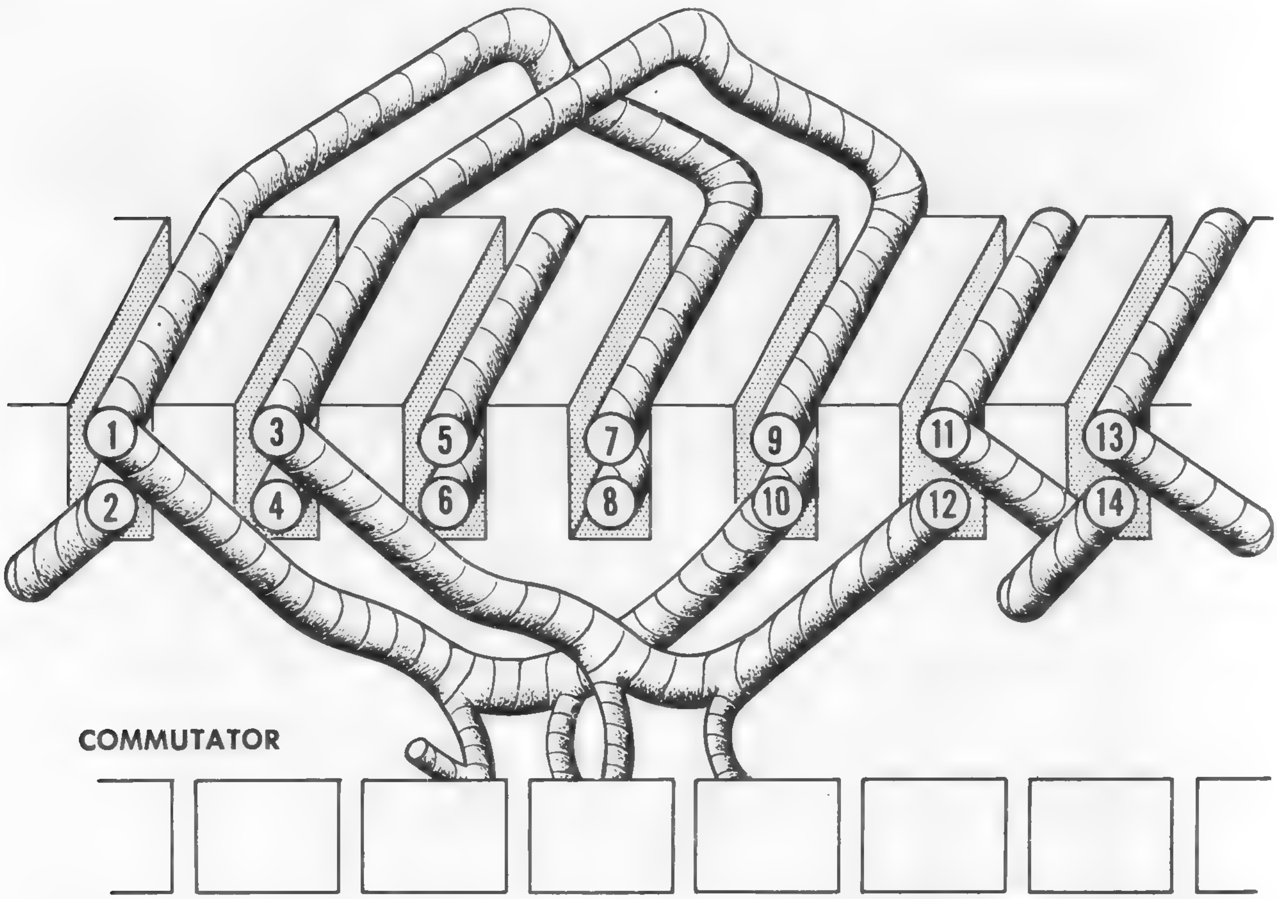


Figure 25.—Section through commutator.

The armature core is made up of sheet-steel discs punched out by a die. These laminations may be held together by rivets, snap rings on the shaft or spider, or by end plates and through bolts. A laminated assembly keyed to an armature spider, which is in turn keyed to the shaft, is shown in figure 24.

Commutators operate in conjunction with carbon brushes to rectify the alternating current of the armature windings and make it available as direct current for external circuits. Commutators are made up of wedge-shape sections insulated from



Courtesy of McGraw-Hill Book Co., Inc. New York, N. Y.

Figure 26.—Simplex lap winding.

each other by thin layers of mica. The segments are firmly held together by clamping flanges, which pull them inward when the flanges are drawn together by through bolts or cap screws. One type of construction is illustrated in figure 25.

The flanges are insulated from the commutator bars by two collars or rings of built-up mica. Longitudinal slots are provided at the end of each commutator segment for insertion and soldering of coil leads. These slots are usually in the raised portion of the commutator bars, known as the riser, which is at the end nearest the windings.

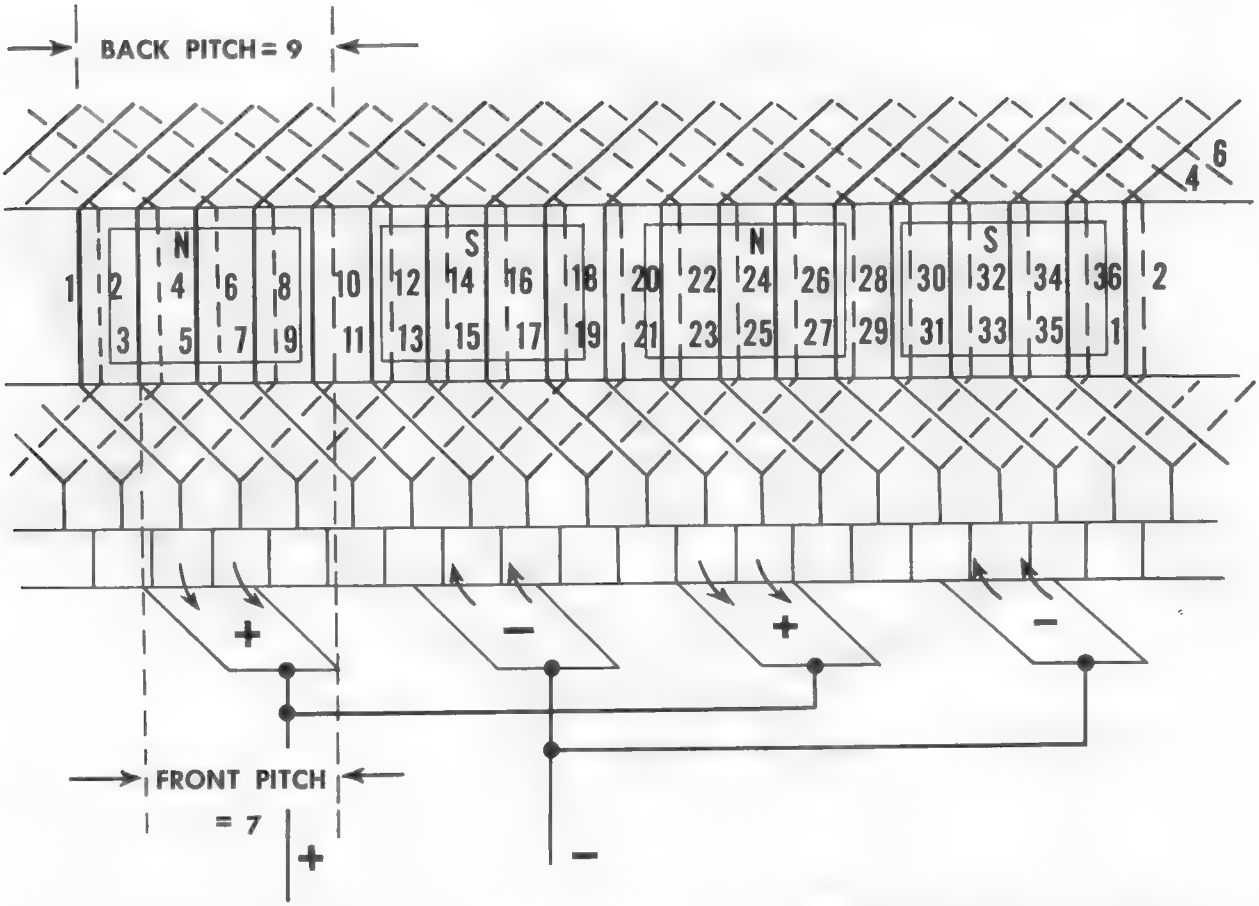
Armature Winding

Direct-current armatures are usually wound with form-made coils. These coils are wound on machines, and the turns are then bound together with linen tape. Another machine is used to bend the coils into the proper shape, this shape corresponding to the coil span and the type of winding used. The ends of each coil are left bare so that they may be soldered into the commutator bars.

One method of placing the coils in the armature core slots and connecting the ends in the commutator bars is shown in figure 26. The winding shown is the type most commonly used with ship's service d-c generators; it is called a *simplex lap winding.*

There are certain terms used in armature winding that describe the relationship existing between coils, poles, and commutator bars. These terms are defined as follows:

1. *Winding element.*—That group of wires that constitute the side of a single coil inserted into an armature core slot.
2. *Pole pitch.*—The distance between the centers of adjacent poles expressed as the number of core slots.
3. *Back pitch.*—The number of winding elements spanned by a single coil.



Courtesy of McGraw-Hill Book Co., Inc., New York, N. Y.

Figure 27.—Four-pole lap winding.

4. *Front pitch.*—The number of elements spanned by the two coil sides connected to a single commutator bar.
5. *Commutator pitch.*—The number of commutator segments advanced by a winding for each complete turn.

In figure 27 the armature is shown as a flat surface. Each line of the winding represents a winding element, the bottom elements of the core slots being even numbers and the top elements odd numbers.

There are 36 winding elements, 18 core slots, and 18 commutator bars. The pole pitch is 4½ slots; the back pitch, 9 winding elements; the front pitch, 7 winding elements; and the commutator pitch, 1.

The span of a coil is equal or nearly equal to the pole pitch so that when one side of a coil is under a north pole, the other side is under a south pole. A saving in end connections and slightly better commutation results if the coil span is made less than the pole pitch.

Practically all armature windings are designed in this way and are called *fractional-pitch windings*.

Inspection of figure 27 will show that the coils are interconnected at the commutator bars to form a series loop. This loop is split up into a number of parallel circuits equal to the number of poles and brushes of the generator.

When coils are placed in the slots of the armature core, they must be insulated from each other and from the laminated iron of the core. One type of slot insulation used on naval shipboard generators is shown in the view of armature slots in figure 28.

Brushes and Brush Rigging

The brushes, which ride on the commutator and convey the generator load current, are made of carbon. To decrease the electrical resistance, the upper portion of brushes is usually copperplated,

and this plating is connected to the brush holder by a pigtail made of copper ribbon.

Brushes are held in place by brush-holders, which are designed to permit up and down motion of the brush so that it can follow any irregularities in the commutator surface. An adjustable spring is provided to maintain satisfactory brush pressure on the commutator.

A ship's service generator has several brushes arranged in a line across the width of the commutator at each neutral point, rather than a single large brush to carry the load current. The individual brush-holders are attached to a common brush-holder bracket. Brush-holder brackets are in turn mechanically connected into one brush-rigging assembly by the brush-holder yoke. This yoke is fastened to the frame by bolts passing through slots in the yoke so that the yoke may be shifted in either direction in order to obtain the best possible position for commutation and voltage regulation. A typical brush holder and brush-rigging assembly is shown in figure 29.

Generator Enclosures

Direct-current generators for naval shipboard services are usually of the open, drip-proof type with natural or integral fan cooling. In figure 30, which illustrates a typical ship's service generator set, it will be noted that the generator yoke is also the frame and that sheet-metal drip shields form the remainder of the enclosure. This permits a free circulation of air and also makes the brushes and commutator accessible for frequent inspections.

Typical Ship's Service Generator

An assembly drawing of a 300-kilowatt ship's service generator is reproduced in figure 31. This drawing illustrates the assembly of the component

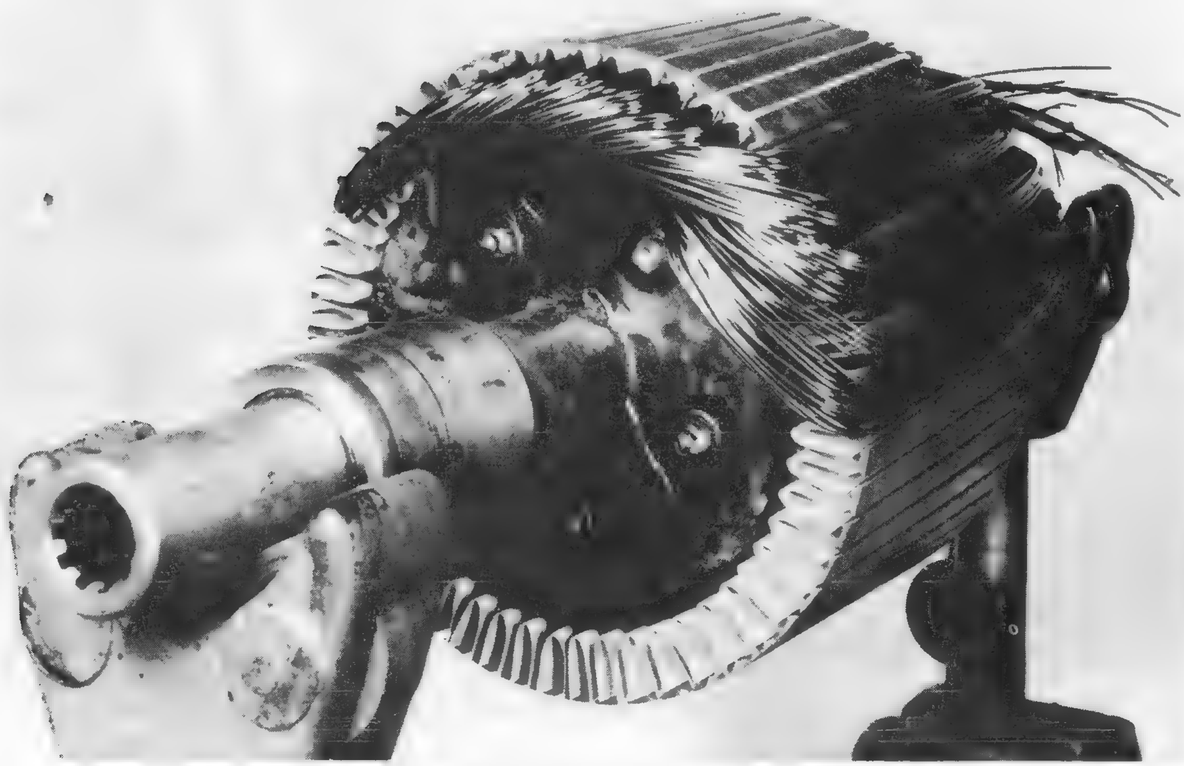
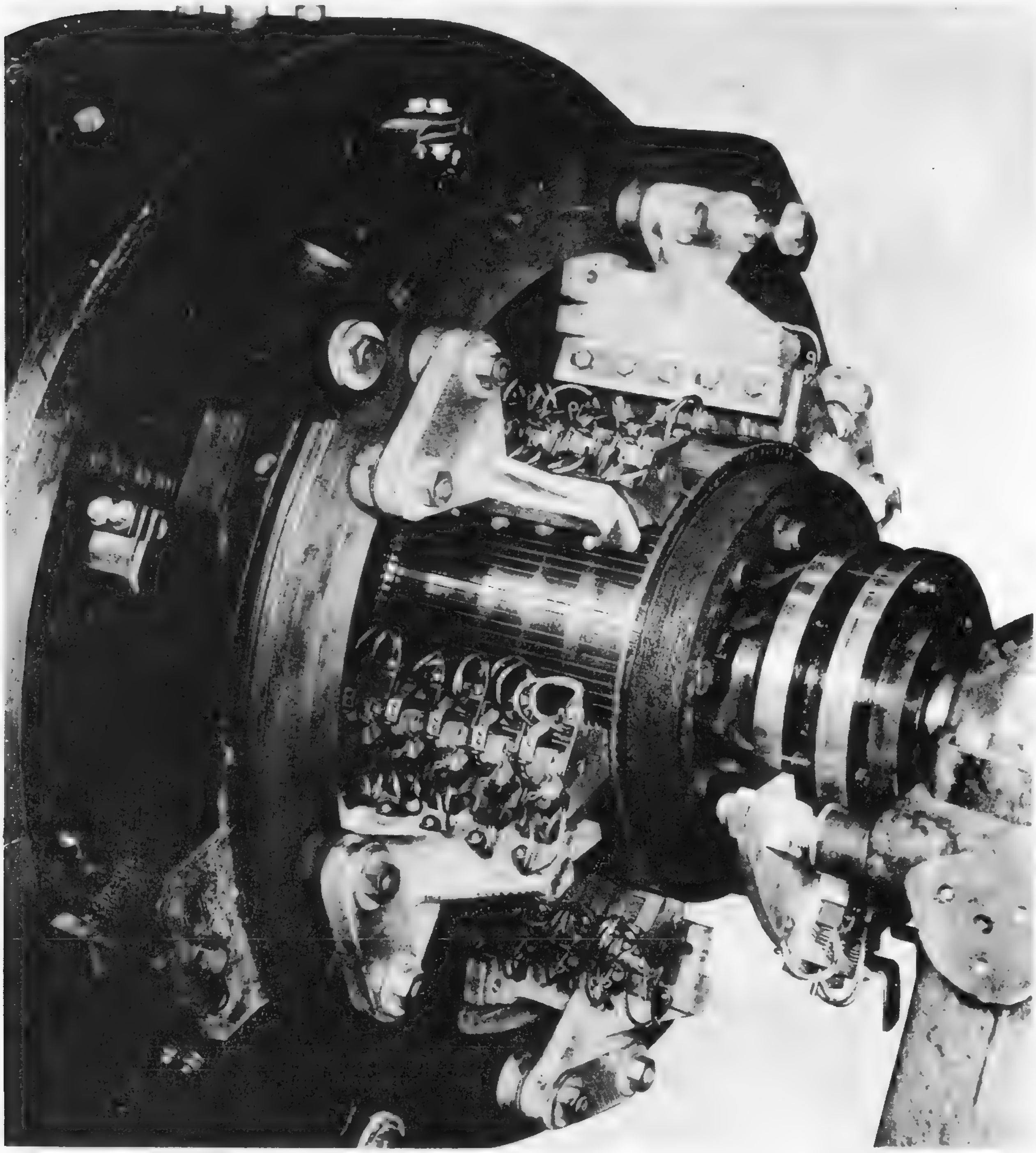


Figure 28.—Armature slot insulation.



Courtesy of General Electric Co.

Figure 29.—Brush holder and brush-rigging assembly.

parts of d-c generators described in the preceding discussion. It also shows those features which are characteristic of marine construction. These are as follows:

1. Open construction with drip-proof shields.
2. Generator terminals brought out to a convenient drip-proof connection box.
3. Brush-holder bracket design and provision for shifting the brushes by slotted hole and bolt connection of the brush yoke with the generator frame.
4. Collector rings and brushes for bringing out generator neutral.
5. Jack screws provided for adjusting shaft alinement.

A cross check between the assembly drawing of figure 31 and the bill of material will bring out other details of construction.

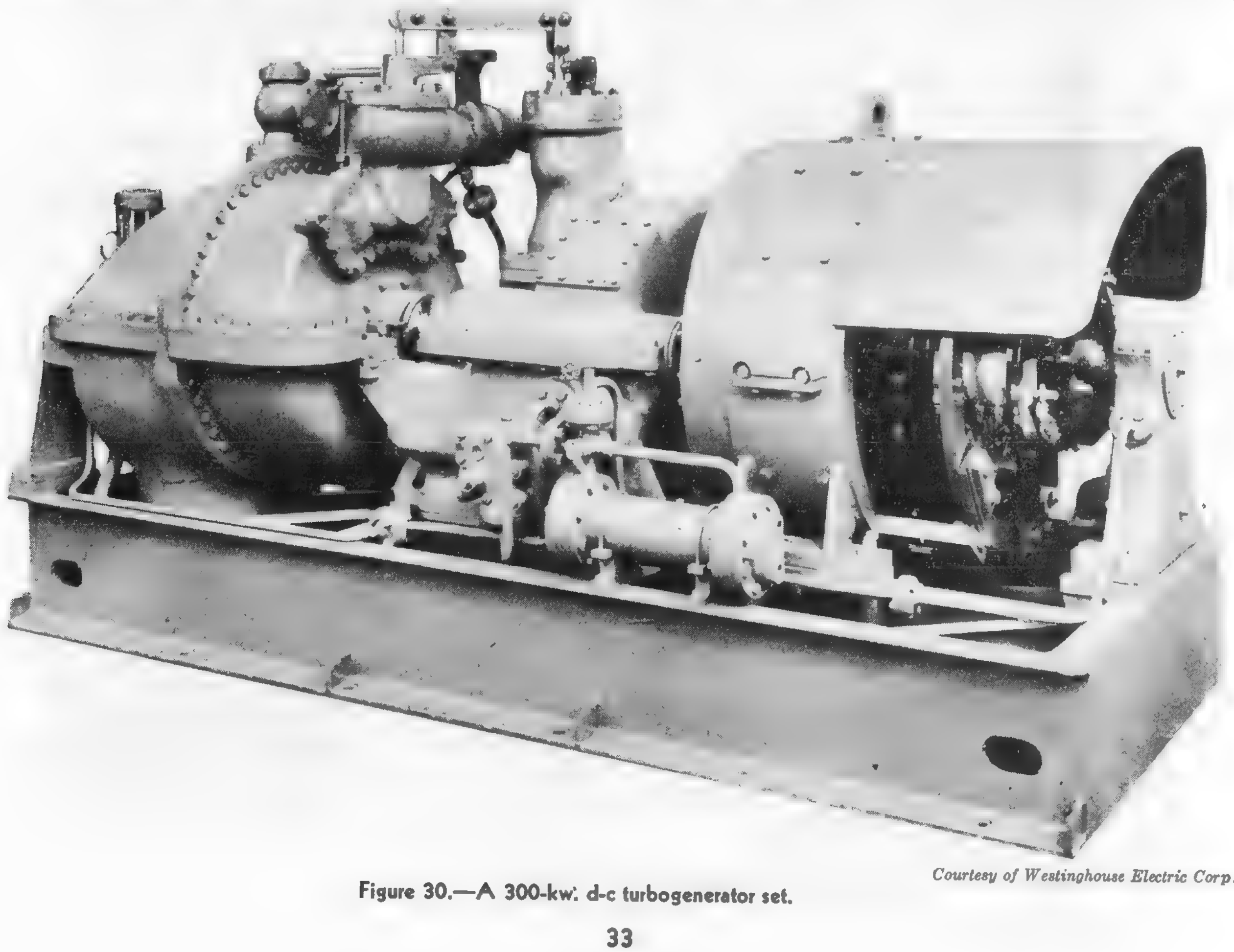
Prime Movers

Ship's service or emergency d-c generators on naval vessels are driven by steam turbines or Diesel engines. On steam-propelled vessels the ship's service generators are turbine driven and the emergency generators are Diesel-driven. The ship's service and emergency generators on Diesel-propelled vessels are all Diesel-driven.

Because of the high operating speed of steam turbines (between 5,000 and 12,000 revolutions per minute), a set of reduction gears are used between the turbine and generator. These gears on a typical 300-kilowatt generator set have a ratio of 8.343 to 1 and are designed to operate with a generator that has a rated speed of 1,200 revolutions per minute.

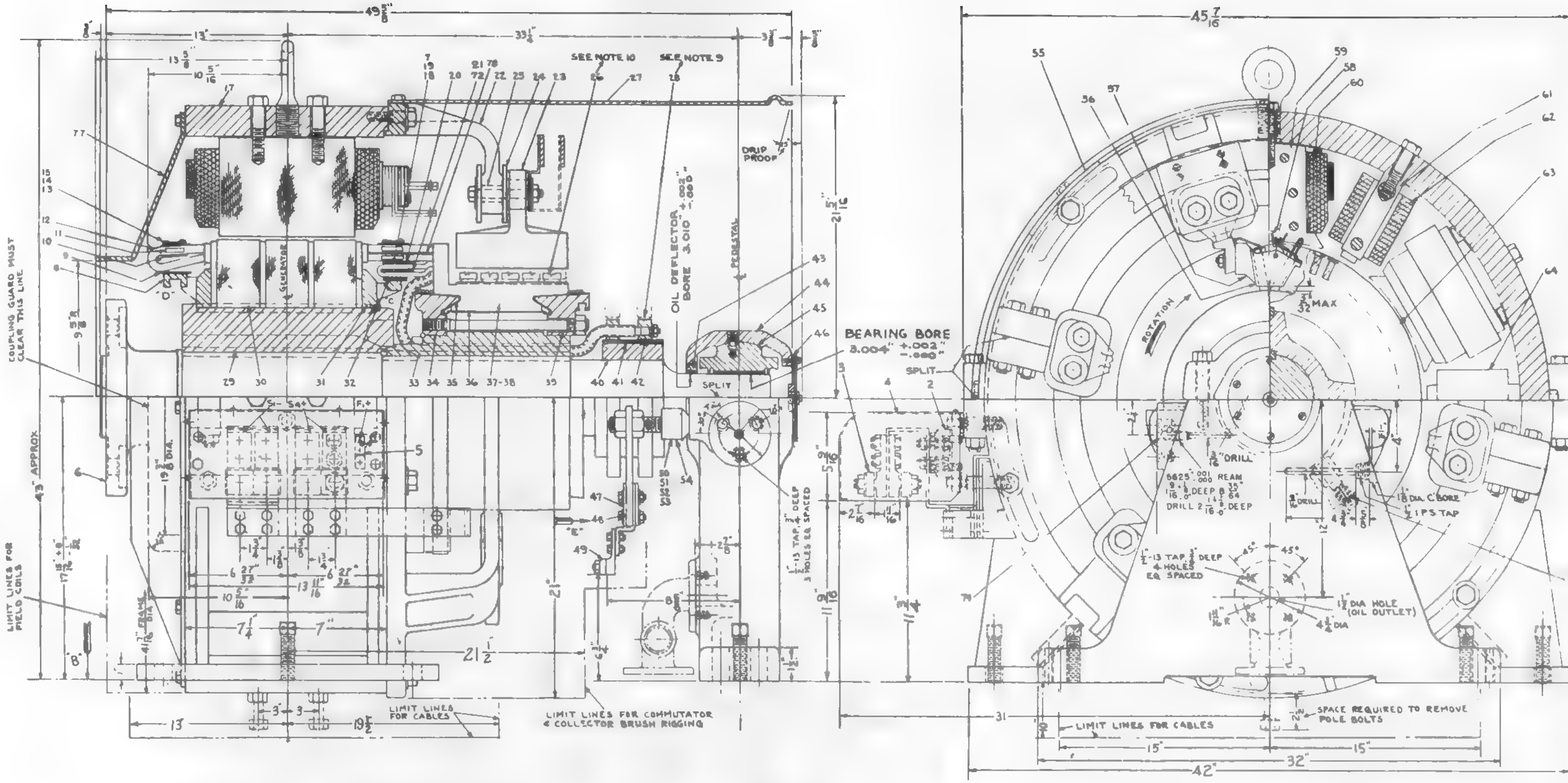
Diesel-engine generators generally have the engine coupled directly to the generator shaft. The operating speeds of these sets range from 400 to 1,800 revolutions per minute, the rated speed being determined by the speed of the engine.

The operation of the prime mover is of considerable importance in the performance of the generator. The speed of the set is entirely controlled from the prime-mover end, and the speed-governing



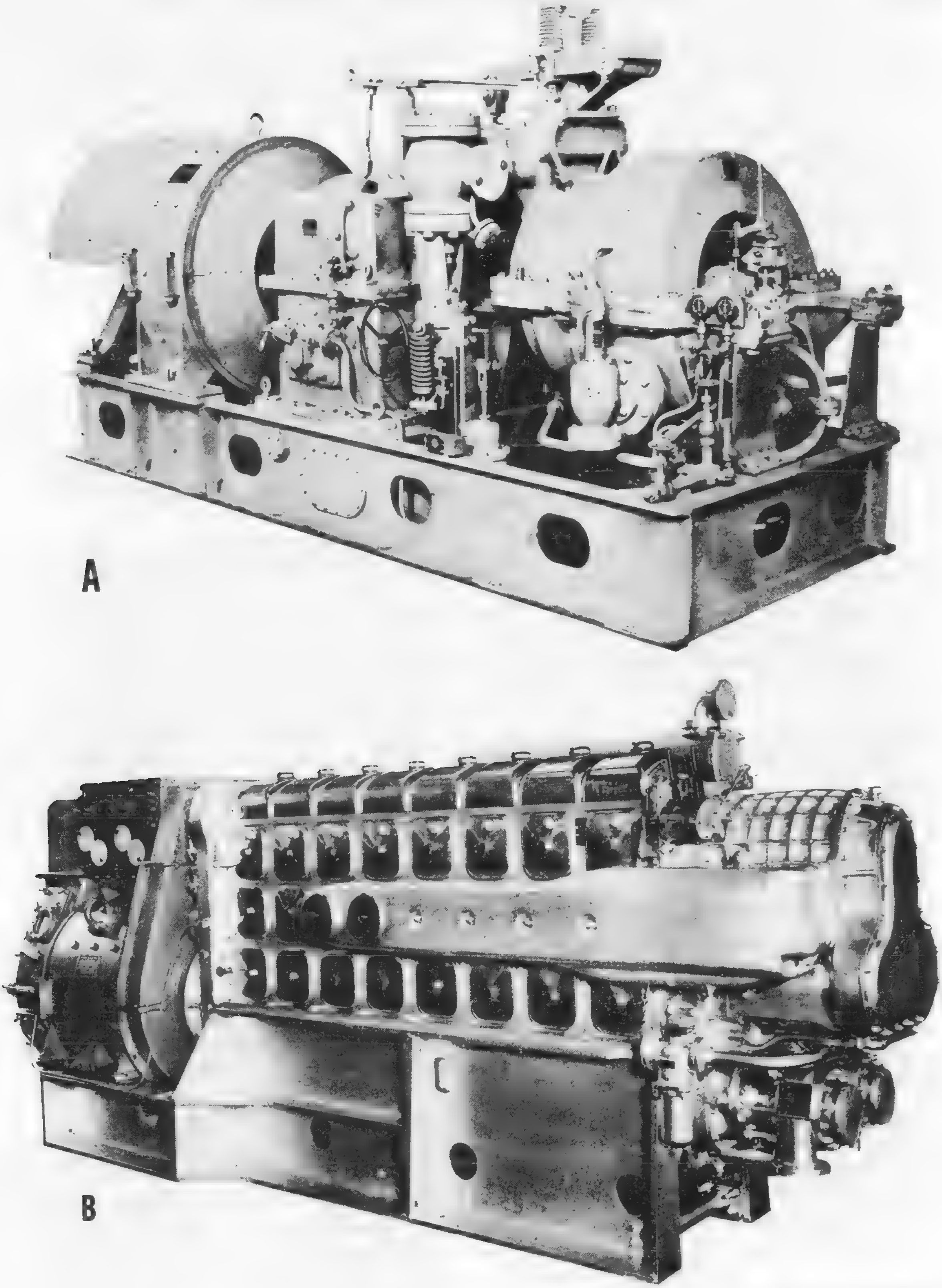
Courtesy of Westinghouse Electric Corp.

Figure 30.—A 300-kw. d-c turbogenerator set.



PIECE NO.	NAME OF PIECE	NO. WANTED PER UNIT	NO. WANTED SPARES PER SHIP
1	ASSEMBLY OF GENERATOR	X	
2	CONNECTION BOARD	1	
3	LINE TERMINAL (BURNDY QIKLUG QA40-2B)	8	
4	CONNECTION BOARD COVER	1	
5	FIELD TERMINAL (BURNDY QIKLUG QA4C-2B)	1	
6	SHAFT	1	
7	FILLER RETAINING TAPE	69	
8	ARMATURE FLANGE (BACK) CAST OR FABRICATED	1	
9	ARMATURE FLANGE INSULATION (BACK)	1	
10	INSULATION BETWEEN TOP & BOTTOM (BACK)	1	
11	ARCH BINDING	207	
12	ARMATURE COIL	69	
13	BAND CLIP	14	
14	BAND WIRE	2	
15	BAND INSULATION	2	
16	SLOT ARMOR	69	
17	MAGNET FRAME (UPPER & LOWER HALF)	1	
18	EQUALIZER RINGS	69	
19	EQUALIZER COVER	1	
20	INSULATION BETWEEN EQUALIZER & ARM.	1	
21	EQUALIZER INSUL BETWEEN TOP & BOTTOM	1	
22	BRUSH HOLDER YOKE	1	
23	BRUSH HOLDER BRACKET	6	
24	INSULATION WASHER	12	
25	INSULATION BUSHING	12	
26	BRUSH (COMM) NATIONAL CARBON CO.	60	
27	DRIP COVER C E	1	
28	BRUSHES (COLL) NATIONAL CARBON CO.	4	
29	ARMATURE SPIDER	1	
30	ARMATURE PUNCHINGS	498	
31	ARMATURE FLANGE (FRONT)	1	
32	ARMATURE FLANGE INSULATION (FRONT)	1	
33	COMMUTATOR SHELL CAST OR FABRICATED	1	
34	CLAMP RING (BACK)	1	
35	CONE	2	
36	SHELL INSULATION	1	
37	COMMUTATOR SEGMENT	138	
38	SEGMENT INSULATION	138	
39	CLAMP RING (FRONT)	1	
40	COLLECTOR SHELL	1	
41	COLLECTOR INSULATION SHELL	1	
42	COLLECTOR RINGS	2	
43	OIL DEFLECTOR (UPPER & LOWER HALF)	1	
44	BEARING PEDESTAL & CAP	1	
45	BEARING — LINING / SHELL	1	
46	GASKET	1	
47	INSULATION BRACE	2	
48	BRUSH HOLDER SUPPORT	2	
49	TERMINAL (BURNDY QIKLUG QA81 2B SPECIAL DRILLING)	2	
50	COLLAR	2	
51	STUD	2	
52	SHELL	2	
53	INSULATOR	2	
54	ASSEMBLY OF INSULATED STUD	2	
55	NAME PLATE	1	
56	BRUSH HOLDER COMPLETE LESS BRUSH (COMM)	X	
57	BRUSH HOLDER BODY (COMM)	30	
58	BRUSH HOLDER SPRING (COMM)	30	
59	MAIN POLE PUNCHINGS	176A	
60	MAIN FIELD COIL	6	
61	COMMUTATING POLE PUNCHING	864	
62	COMMUTATING COIL	6	
63	ASSEMBLY OF ARMATURE	X	
64	ASSEMBLY OF COMMUTATING COIL & POLE	X	
65	BRUSH HOLDER COMPLETE LESS BRUSH (COLL)	X	
66	BRUSH HOLDER BODY (COLL)	4	
67	BRUSH HOLDER SPRING (COLL)	4	
68	ARMATURE SLOT WEDGE	138	
69	SOLDERING BLOCKS	X	
70	AIR GAP GAUGE	X	
71	BRUSH TENSION SPRING BALANCE	X	
72	EQUALIZER FILLING COMPOUND	X	
73	SERIES FIELD JUMPER	6	
74	OIL ORIFICE	1	
75	AIR GAP GAUGE		
76	BRUSH TENSION SPRING BALANCE		
77	COVER PE (TOP & BOTTOM HALF)	1	
78	INSULATION BETWEEN TOP & BOTTOM (FRONT)	1	

Figure 31.—Assembly of 300-kw. d-c generator.



Courtesy of General Electric Co.

Figure 32.—(A) Turbo generator. (B) Diesel generator.

system must be designed to maintain approximately constant speed under varying load conditions.

Prime mover governors must be adjusted and maintained to provide good speed regulation from no-load to full-load and to prevent hunting when sudden heavy loads are applied or removed. (Hunting is a speed oscillation over a small range, caused by the inability of the governor to respond quickly to changes in load. It is a frequent source of trouble particularly where parallel operation is involved.)

Safety devices are provided on the prime mover for preventing overspeed. On a turbine-driven set a hand-operated trip releases a strong spring, which acts instantaneously to close the turbine throttle valve. An emergency governor which will shut off the steam supply when the speed becomes excessive is also provided.

Diesel engines are provided with an overspeed throttle trip and can be quickly shut down by hand in event that the automatic trip fails to function.

Typical turbo-generator sets and Diesel generator sets are illustrated in figure 32.

Operation

GENERAL

Manufacturers' instruction books contain details of construction, operation, and maintenance for the particular generator units installed. These books should be carefully reviewed before starting the equipment for the first time.

Check-off lists prepared from the operating procedures of these publications prevent personnel from overlooking vital steps which can damage equipment. Check-off lists are particularly useful on ships that have been in commission only a short time or where the operating crews are realtively inexperienced.

Operating procedures as outlined in instruction books or in Bureau of Ships manuals are usually divided into five groups as follows:

1. Preparation for initial starting.
2. Starting.
3. Parallel operation.
4. Shutting down (single generator operation).
5. Shutting down (parallel operation).

Preparation for Initial Starting

The preparation for initial starting consists of a careful inspection of all generator parts to detect any faults in adjustments that may have occurred during transportation from the factory or installation aboard ship. These adjustments are concerned primarily with tightness of connections, brush adjustment, insulation strength, clearances between rotating and stationary parts, and lubrication.

Starting

When the machine is ready for running, the prime mover is started and brought slowly up to speed. During this period the generator is checked for vibration, air circulation, lubricating-oil pressure and temperature, and the smoothness with which brushes ride on commutator and collector rings.

With the generator running at rated speed the shunt field has full rheostat resistance in series with it. Under these conditions the generator voltmeter should show a little voltage; but if the reading is zero, the field connections should be checked with the wiring diagram. If the connections are correct and the voltage still does not build up, then the residual magnetism of the main field poles has either been lost or reversed. To replace the correct residual magnetism, it is necessary to excite the field momentarily from an external source, using the same polarity as indicated on the connection diagram.

If the field circuit is functioning properly, the generator voltage can be brought up to its rated value with the field rheostat. The circuit breaker and then the disconnect switches, if any, are closed to put the generator on the line. The loading of the machine should be gradual, allowing sufficient time between increments of one-fourth load to observe commutation, heating, and the like.

Parallel Operation

In paralleling a generator with another one already connected to the line and to the load, the voltage of the incoming machine is brought up to the same value as the line voltage, and the circuit breaker and disconnect switches are closed. (See figure 33.) Distribution of load between the two machines is made by adjustment of the two field rheostats.

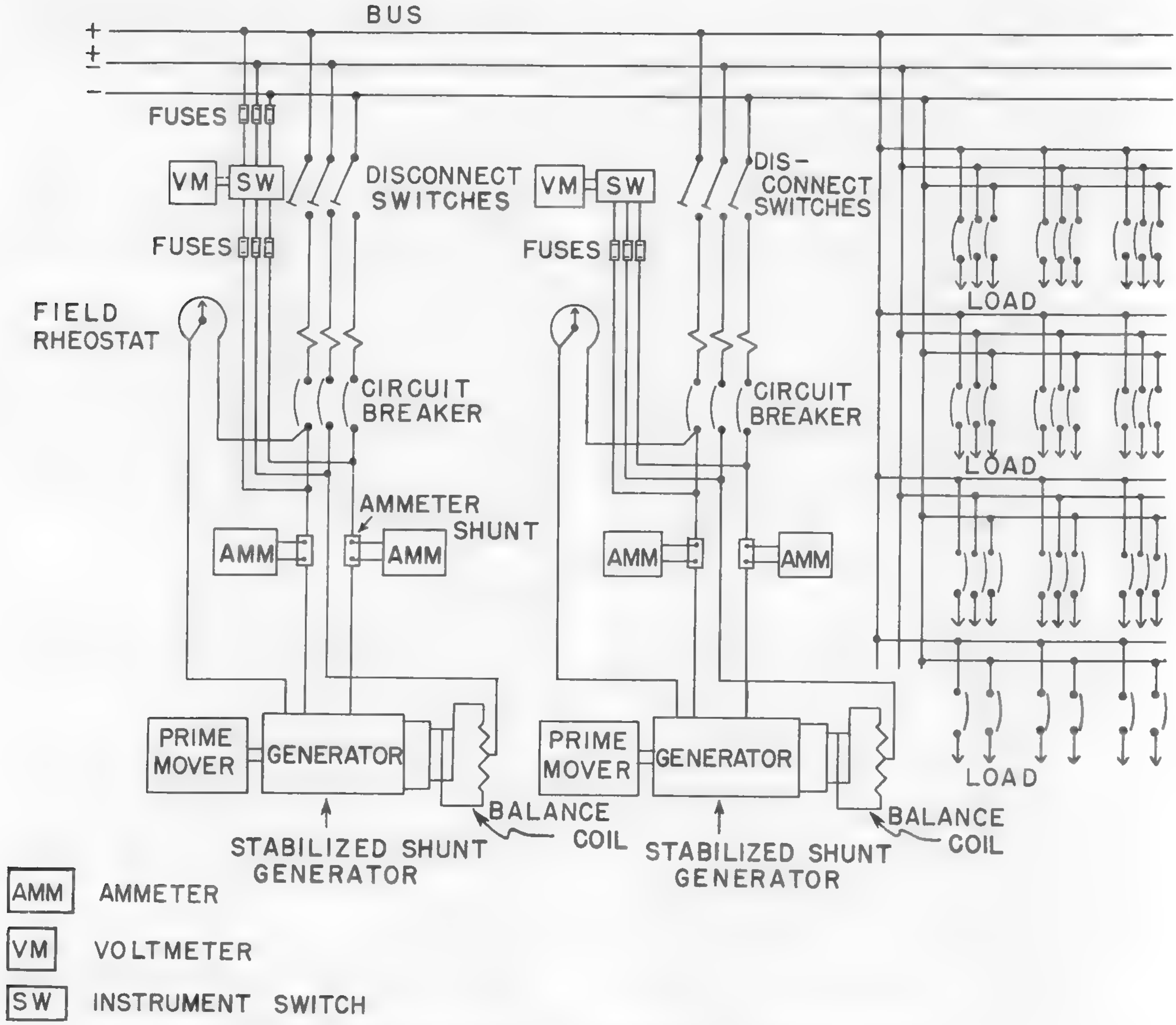


Figure 33.—Typical wiring diagram of switchboard and d-c generator connections.

Shutting Down

The usual procedure for shutting down a generator operating on the line by itself is to gradually remove the load, lower the voltage, trip the circuit breaker, open the disconnect switches, and secure the prime mover. (See figure 33.)

If a generator is to be disconnected from the line where it is operating in parallel with another unit, gradually cut in shunt field resistance to reduce the load to a minimum. The circuit breaker is then tripped, the disconnect switches opened, the voltage lowered, and the prime mover secured.

Maintenance

INSPECTIONS

Generators should be inspected at regular intervals. Each inspection should include a check for cleanliness; smoothness of operation; and condition of brushes, commutator, collector rings, bearings, and bolts. Insulation tests should be

conducted once every 2 weeks and never less frequently than once a month.

Annual inspections should be more thorough than the general inspections carried out during the year. At this time the end covers should be removed, and very close examination made of windings, commutator, and collector-ring surfaces. Brushes and brush holders should be cleaned; and where brushes show undue wear, they should be replaced with new ones. The commutator should be checked for trueness and the mica between commutator bars examined to see that it is slightly below the commutator surface. All bolts and connections, including those for the foundation, coupling, armature, and field pieces, should be tested for tightness. The air gap between the stationary and rotating parts should be checked for uniformity. Bearings should be opened and inspected for wear and evidence of improper lubrication.

Commutator

If the commutator is slightly rough, brushes should be raised and the commutator lightly sandpapered as it turns. It should then be wiped clean with a piece of canvas before the brushes are replaced. Cotton waste should never be used.

If the commutator is too rough for sanding and a revolving-wheel grinder is available, this may be used with a fine sandstone wheel.

If there is no revolving-wheel grinder available, sandstone may be applied in the same manner as sandpaper; or it may be held in a rigid tool position while the armature is turned. The sandstone is shaped to conform to the commutator surface.

Commutators which have been in service develop a high degree of surface polish owing to the action of the brushes. This polish is essential to smooth operation and good commutation under full-load conditions. After sanding or stoning a commutator, the polish is lost and must be regained by running the machine at low values of load over long periods of time. The recommended procedure is to run at light load for 24 hours and at half load for an additional 24 hours. If the commutator then presents a high and uniform polish, the machine may be fully loaded.

When the wear on a commutator is such that the mica between commutator bars is flush with the commutator surface, the mica should be undercut. This can be done with a small hacksaw blade or similar tool by scraping away a small amount of the mica between bars until it is slightly below the commutator surface. The commutator surface should be sanded after undercutting the mica.

Collector Rings

Collector rings for the generator neutral should be kept free from metal particles, dust, and oil. The perfect cylindrical shape of the rings should be maintained, and they should run true with a hard polished surface.

Sometimes an imprint of brushes is found on collector rings. This may be due to the action of acid fumes or corrosion on unprotected rings during an extended shutdown. Any black spots that appear on the surface of the collector rings should be removed by rubbing lightly with fine sandpaper to avoid eventual pitting of the rings and the necessity for regrinding.

Brush Neutral

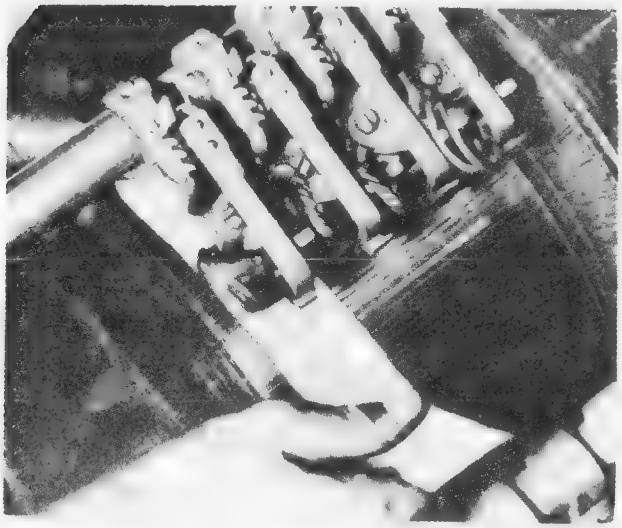
Brush setting, as determined at the factory, is marked by a line across the brush-holder yoke and the adjacent stationary part. In general this setting will be found satisfactory.

If it is found necessary to adjust the commutator brushes to attain proper commutation and voltage regulation, the brushes should be set on a neutral plane and then shifted slightly one way or another until the best results are obtained.

Sanding Brushes

When new brushes are installed or when old brushes show poor contact, the brushes should be carefully fitted to the commutator by sanding. This is done by lifting the brushes in each brush holder sufficiently to permit a sheet of sandpaper to be inserted. Grade 1½ sandpaper is recommended for the roughing cut; Grade O for the final cut. The sandpaper should be fitted so that it follows the curvature of the commutator; and when all brushes are to be sanded, the sandpaper should be wrapped completely around the commutator. The sandpaper should be drawn in a heel-to-toe direction with respect to the brush. The toe of a brush is the edge of sharper angle in the direction of rotation; the heel is the opposite edge, as shown in figure 34.

After the sandpaper has been inserted into the proper place, those brushes which are to be sanded



Courtesy of General Electric Co.

Figure 34.—Sanding brushes.

are dropped into place, with the brush-holder springs holding them tightly against the sandpaper. The sandpaper is then drawn in the direction of rotation. All carbon, dust, and sand particles should be blown out of the machine after the brush-sanding operation.

Insulation Resistance

A record of insulation resistance taken over a period of time is the best method of determining whether the insulation is tending to break down.

The field and armature should be measured separately. When measuring insulation resistance of the field, all leads to the field should be disconnected. When measuring insulation resistance to the armature, however, the armature may be adequately isolated by lifting all the brushes.

The simplest method of measuring insulation resistance is to use a *megohmmeter* or "megger," an instrument that indicates the resistance directly in megohms. This instrument has a hand-crank magneto that supplies its own voltage for making the test.

The safe insulation resistance of field poles and armature varies for different generators, depending on the voltage rating and also on the conditions under which the generators are operating. All manufacturers' instruction books contain the original factory test data on a particular machine. After installation, the machine is also subjected to the insulation tests in the shipyard, and records of these tests are available to engineering personnel aboard ship.

Any sharp drops in insulation resistance that are indicated by measurements made over a period of time should be carefully investigated. If the drop continues beyond safe limits, the machine should be taken out of service and all windings dried either by baking out in an oven or by passing current through the windings.

Disassembly and Reassembly of Generator

The procedures for disassembly and reassembly of generators are given in manufacturers' instruction books and should be carefully followed in the sequence outlined.

CHAPTER 4

ALTERNATING-CURRENT GENERATORS

Operating Principles

REVIEW OF A-C GENERATOR PRINCIPLES

As stated in chapter 3, alternating-current generators are usually designed with a rotating field and a stationary armature; this eliminates the need for brushes and slip rings to carry the full-rated load current. With alternators of any appreciable size, this is a distinct advantage. Besides eliminating the maintenance on high-current-capacity slip rings and a considerable number of brushes, the dangers of open or short circuits are reduced to a minimum.

The rotating field of an alternator is energized with direct current through brushes and slip rings. Direct current is provided by a small generator driven by the main generator prime mover. This d-c generator is called an *exciter* and is usually mounted on the end of the main generator with its shaft coupled to an extended end of the main shaft.

The frequency developed by an alternator is a function of the speed and the number of poles and is equal to

$$f=\frac{pn}{2(60)}$$

where p = number of poles
n = speed in revolutions per minute
f = frequency in cycles per second

The number of poles for which an a-c generator for a given frequency is designed depends on the speed of the prime mover. The standard frequency for naval ships is 60 cycles.

Alternating-current generators are either single phase or polyphase. Single-phase generators are seldom used because the power delivered by such machines is pulsating and because polyphase generators for the same rating are generally smaller in size.

Three-phase alternators have been selected as standard for ship's service and emergency generators because the three-phase system has the least number of conductors of any symmetrical polyphase system, permitting considerable savings in both cost and weight in the distribution system as a whole.

Connections of Three-Phase Generators

The windings of three-phase alternators are connected either *delta* (Δ) or *wye* (Y). Windings which are connected with one common junction point and three free ends are connected wye. In the delta connection, windings are interconnected to form a loop, and the common point of any two windings is brought out as a line connection. The interconnection of phase windings to form wye or delta connections and the vector relationships between phase voltages, line voltages, phase currents, and line currents are shown in figure 35.

Rating

The maximum output of any a-c generator is limited by its mechanical strength, by the temperature of its parts that is produced by losses, and by the permissible increase in field excitation necessary to maintain rated voltage at some specified load and power factor. Usually the limit of output is fixed by the rise in temperature under load.

Ship's service or emergency generators are rated in kilovolt-amperes at the ship's voltage and frequency or in kilowatts at a stated power factor.

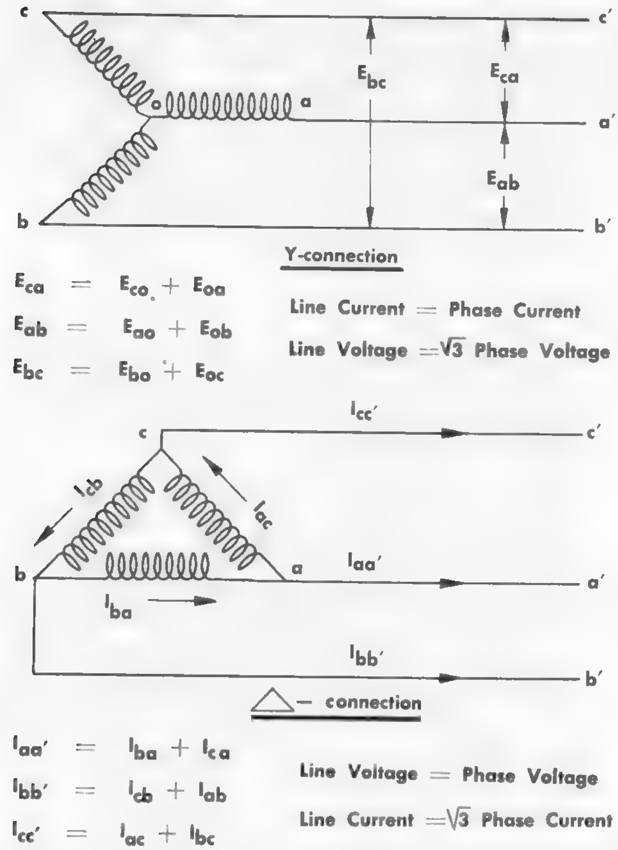


Figure 35.—Line and phase relationships, three-phase a-c generators.

Voltage Regulation

The voltage regulation of a generator is defined as the difference between no-load voltage and full-load voltage divided by the no-load voltage. Percentage regulation is given by

$$\text{percentage regulation} = \frac{E_{NL} - E_{FL}}{E_{NL}} \times 100$$

where E_{NL} = no-load voltage
E_{FL} = full-load voltage

Regulation is positive for both noninductive and inductive loads but is negative for a capacitive load. Regulation on ships where there is usually a relatively heavy inductive load is always positive.

Efficiency

The efficiency of a generator is defined as the ratio of useful electrical output to total input. The power losses which take place within the a-c generator are copper losses in the armature and field windings, core losses, and mechanical losses. The efficiency of a-c generators is notably high, as is shown by the typical guaranteed efficiencies for 1,250-kilovolt-ampere ship's service generators installed aboard *Essex* class carriers. These efficiencies are tabulated as follows:

One-half load	93.80 per cent
Three-fourth load	95.10 per cent
Full load	95.60 per cent

Parallel Operation

As stated in chapter 3, in order for d-c generators to operate successfully in parallel, their voltage characteristics must be drooping or, in the case of compound generators, equalizer connections must be provided. Alternating-current generators in parallel operate on a different principle. Their successful operation in parallel is largely dependent on the speed-load characteristics of the prime movers, a drooping-speed characteristic on each machine with increase in load being required for stable load distribution.

Before two a-c generators can be safely paralleled, three conditions must be fulfilled. The two terminal voltages must be equal, or substantially so; the two machines must be in phase and have the same phase rotation; and the frequencies must be approximately equal. The voltages of the two machines are adjusted by means of the generator field rheostats, and the frequency of each machine is adjusted by changing the setting of its prime-mover governor. A synchroscope is usually provided to indicate the relative differences in frequency between two generators and the relative displacement of their phases. When the synchroscope indicates that the two machines are in phase and operating at about the same frequency, they may be paralleled.

When two a-c generators are operating in parallel, they are said to be synchronized, or operating in step with each other. Paralleled a-c generators are in a stable condition. If they attempt to pull out of step with each other, a current is developed that circulates between the two machines; this causes the lagging machine to accelerate and the leading machine to retard.

The distribution of kilowatt load between two or more generators operating in parallel is controlled by the governor settings. An increase in a governor

setting causes its respective machine to take more load. On large ships governor controls are provided on the main switchboards.

Distribution of reactive load between a-c generators operating in parallel is dependent on the field excitations of the machines. When the field excitation of a machine is decreased, it will transfer reactive load to other machines in proportion to its decrease in field strength. The increase of field excitation will similarly cause a machine to take more reactive load in proportion to the increase in field strength. The usual process of transferring reactive load from one machine to another is to decrease the field excitation on one machine and increase it on the other. In this way, the line voltage can be kept at its original value.

Construction

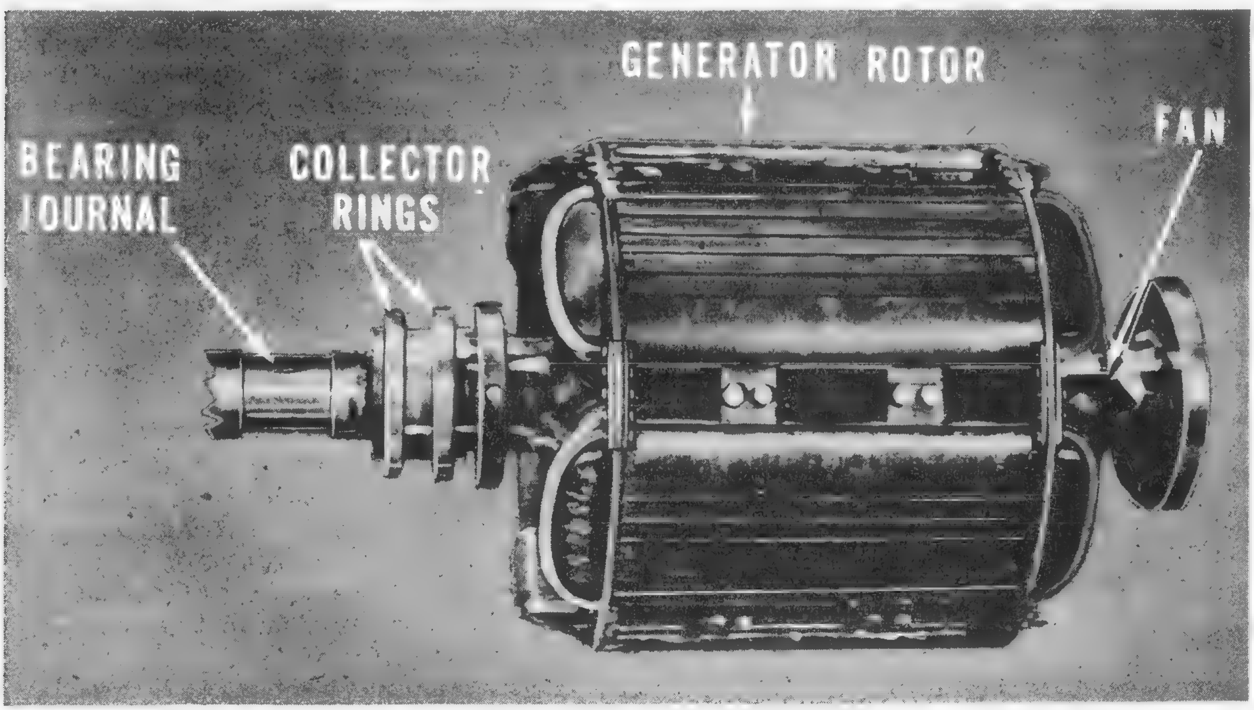
GENERAL

The general construction of a-c generators is somewhat simpler than that of d-c machines since the load-carrying armature windings are stationary and commutation is not required. The number of brushes is reduced to those necessary to carry current for exciting the field, which is a part of the rotating element. Brushes and corresponding collector rings for this purpose are, therefore, fewer in number, as compared with the commutator and brushes of d-c generators.

Rotor Design

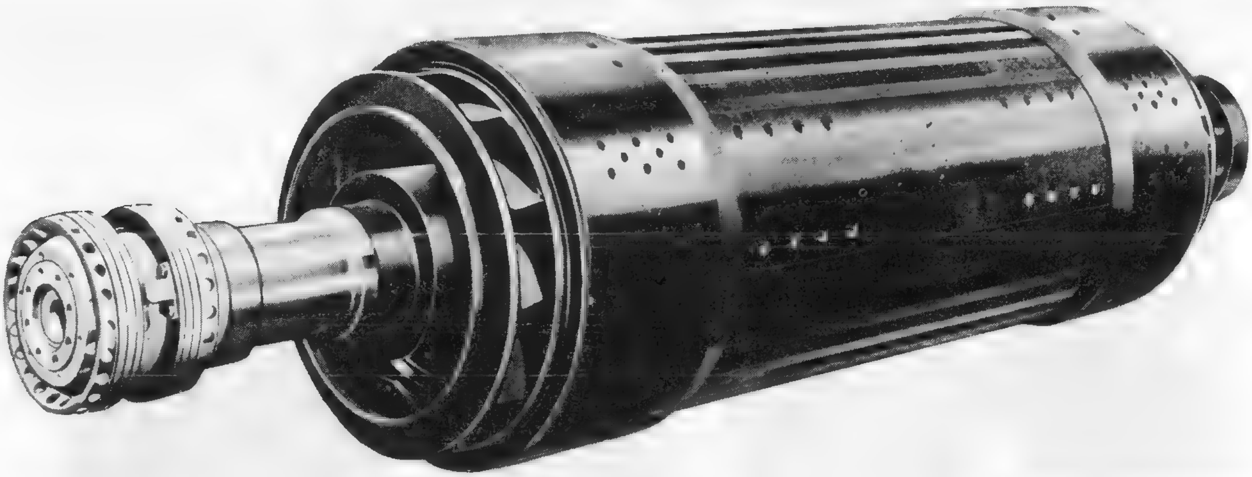
The principal difference between the two general types of alternators in use aboard naval vessels today is in the rotor design. Rotor design is determined primarily by the speed at which the generator is to be driven, but it is somewhat influenced by the rating of the generator.

Diesel generators and some turbo-generators operating at 1,200 revolutions per minute or below employ salient pole rotors. The poles with their windings are separate parts from the rotor spider and are secured to it by dovetails, which are keyed to the spider with steel keys. The rotor spider may be either a separate laminated steel core pressed on, and keyed to the shaft, or a part of the shaft forging itself. Field windings are usually connected in series, and the ends of the circuit are connected to two slip rings insulated from, and



Courtesy of General Electric Co.

Figure 36.—Salient pole rotor.



Courtesy of General Electric Co.

Figure 37.—Cylindrical rotor.

mounted on, the rotor shaft. A typical salient pole rotor is illustrated in figure 36.

An amortiseur or damping winding is provided on all engine-driven and some turbine-driven salient pole generators to dampen out hunting effects when generators are operated in parallel and to equalize flux distribution when an unbalanced load condition exists. These windings are similar to squirrel-cage windings and are placed near the pole face of each field pole.

With turbine-driven generators of large capacity designed to operate at 1,200 revolutions per minute or above, a cylindrical rotor, consisting of a solid steel forging, is generally used. Slots are milled into this forging in which the field coils are imbedded. These coils are usually arranged to form either two or four magnetic poles. A rotor of this type is shown in figure 37.

The diameter of the rotor used with these generators is small, and at high speeds this construction results in better balance, less noise, and less windage. It is also stronger mechanically. With such a small diameter, the rotor length is greatly extended in order to obtain the required field strength, and the surrounding stationary armature is required to have deep slots and forced ventilation to provide for the current and voltage requirements.

Stator Construction

Stator frames are fabricated from rolled-steel sheets and plates. The usual construction provides dovetailed ribs welded at suitable intervals around the inner periphery of the frame for the purpose of securing the stator punchings which make up the armature core. Each punching has dovetailed slots in its outer periphery to locate and key it to the dovetailed ribs.

The stator core consists of thin laminations of low-loss silicon steel with open slots punched around the inner periphery to receive the stator winding. The laminations are usually stacked in the stator frame against a keyed flange at one end and are clamped at the other end by a similar flange keyed to the dovetailed ribs.

Stator coils are form wound and present an appearance similar to those provided for d-c armatures. They are held in the armature slots by slot wedges, and the ends are blocked against each other. All coils are lashed to binding rings which prevent movement under heavy-load surges or short-circuit conditions. The general appearance of stator frames and windings for salient pole and cylindrical rotor machines is shown in figure 38.

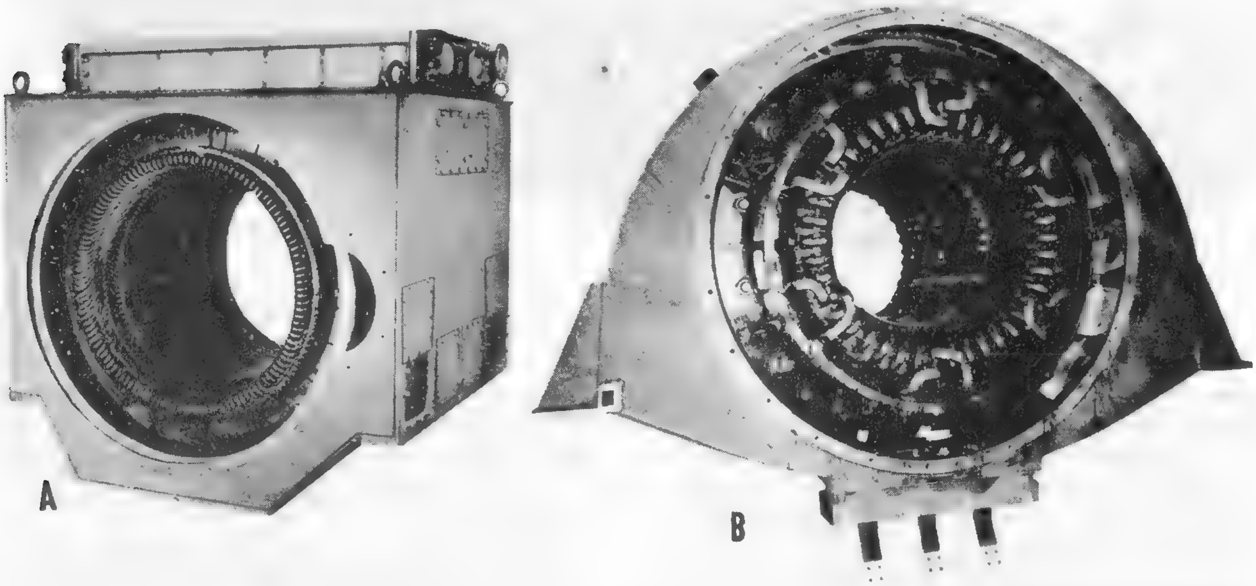
Enclosures

Alternators aboard ship in ratings 500 kilowatts and above are usually totally enclosed for the purpose of securing a closed air-circulating system operating in conjunction with an air cooler and to protect the armature windings. On a typical generator the entire enclosure is made up of a portion of the frame, a cooler housing bolted to the top of the frame, and split, double enclosing end bells bolted to each end of the frame. The surface air

cooler within the enclosure is usually mounted on top of the stator frame. This type of assembly is illustrated in figure 39.

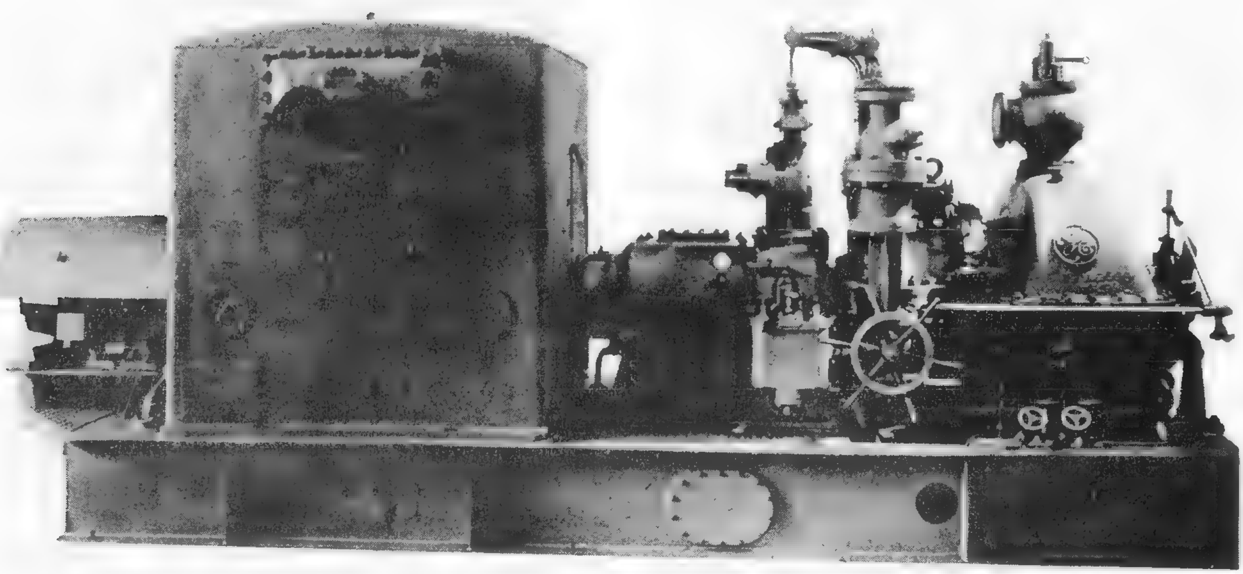
Air Coolers

The air cooler consists of double-wall fin tubes through which cooling water flows. Water flows



Courtesy of General Electric Co.

Figure 38.—Stators of salient pole (A), and cylindrical rotor (B) alternators.



Courtesy of General Electric Co.

Figure 39.—Exterior view of 1,250-kva. alternator.

in the inner tubes, and the outer tubes provide the necessary protection against leakage in the inner tubes.

Ventilation for Enclosed Generators

Enclosed generators are ventilated by means of fan blades mounted on each end of the rotor. The air enters the generator through the fans, is forced into the air-gap, and then flows radially outward through ducts in the stator core to a space outside the core. It then passes upward through the cooler and flows back down inside the air shields to the fan inlet and is recirculated.

Collector Rings and Brushes

The collector-ring assembly generally consists of two forged-steel or brass rings shrunk on over a mica shell which is molded on a forged-steel shell. The leads come out through slots in the shell and connect to the corresponding leads of the field winding. A small steel ring shrunk on the same shell clamps the leads in place.

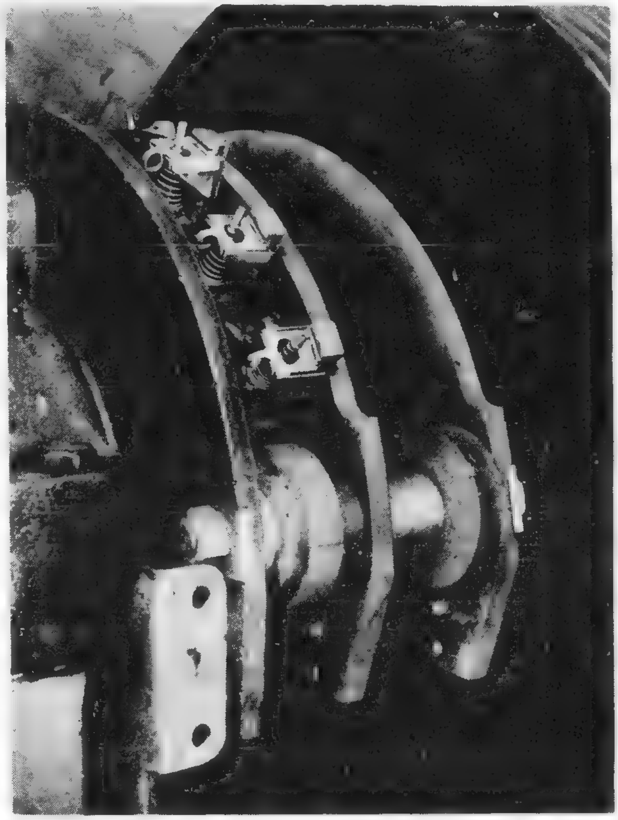
The brush-rigging assembly consists of two brush-holder supports mounted on insulated studs which are attached to the pedestal-bearing cap. The number of brushes for each collector ring varies in accordance with the rating of the generator. Adjustable springs are provided with each brush-holder for adjustment of brush pressure against the collector-ring surface. A typical brush rigging for collector-ring assembly is shown in figure 40.

Electric Heaters

When electric heaters are considered necessary, they are installed within the generator enclosure on the generator stator frame. These heaters are used to keep the generator warmer than its surroundings and to prevent the condensation and accumulation of moisture within the generator when it is not in operation.

Bearings

The generator rotor is supported on the collector-ring end by a pedestal bearing which is usually self-aligned, ball-seated, and babbitt-lined. It is split horizontally to facilitate assembly and disassembly, and it is clamped to its seat by the bearing cap.



Courtesy of General Electric Co.

Figure 40.—Brush rigging for collector-ring assembly.

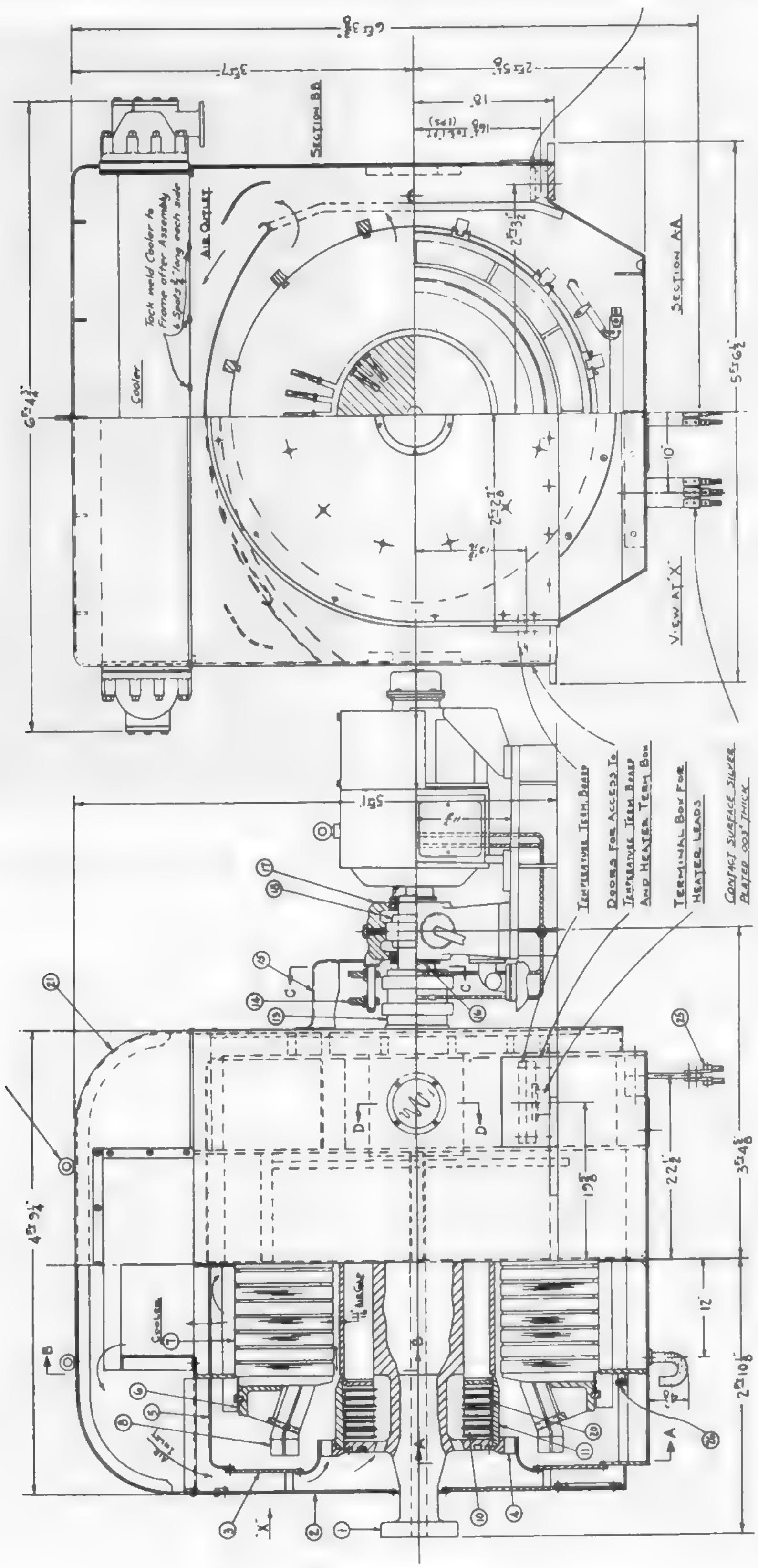
Typical A-C Generator

The section views of figure 41 show an assembly of all parts previously discussed, together with other detailed construction features.

Stator Windings

The stator windings of an alternator are quite similar to those of a d-c armature but are much simpler. The necessity of making connections to commutator bars and the use of many coils of a few turns each to obtain commutation without sparking results in a rather complex winding for d-c machines. The alternator, on the other hand, has no problem of commutation and has but few coils, as compared to a d-c generator of similar size.

The types of coils used in a stator winding are practically identical with the types used with d-c armatures. (See chapter 3, figure 28.) Each coil is form wound with the required pitch to suit the



BILL OF MATERIAL			
PIECE NO	NAME OF PIECE	NO WANTED ORIGL	NO WANTED SPARE
1	Shaft	X	
2	Air Shield Outer	X	
3	Air Shield Inner	X	
4	Air Fan	X	
5	Stator Frame	X	
6	Stator Flange	X	
7	Stator Punchings	X	
8	Stator Winding	X	
9	Stator Connection	X	
10	Rotor Winding	X	
11	Retaining Ring	X	
12	Centering Ring	X	
13	Collector Assembly	X	
14	Brush Holder Rigging	X	
15	Drip Cover	X	
16	Oil Deflector	X	
17	Bearing Cap	X	
18	Bearing	X	
19	Pedestal	X	
20	Radiating Plates & Blocks	X	
21	Cooler Cover	X	
22	Rotor Assembly	X	
23	Temperature Term. Board	X	
24	Connection Strap	X	
25	Qirluo Terminal	X	
26	Heater Arrangement	X	
27	Field Leads	X	

Figure 41.—Assembly drawing of 1,250-kva. alternator.

requirements of design, and is suitably taped for insertion in the stator slots. When all coils have been properly installed in the stator, there will be two free ends of wire for each coil extending from one side of the stator winding. These free ends are then connected to form groups of coils to suit the number of phases, voltage, and current requirements.

Three-phase windings are merely three single-phase windings symmetrically spaced around the stator with a relative displacement between successive phases of 120 electrical degrees. If the principles of single-phase windings are understood, there will be little difficulty in understanding three-phase windings.

Single-phase lap and wave windings are illustrated in figure 42. Inspection of these two windings shows that each has the same number of series-connected conductors between terminals. If the speed and field excitation of two machines wound in this way are equal, the induced electromotive forces will be equal. Because the connections of a lap winding are somewhat simpler, this type of winding is used almost exclusively.

A typical three-phase winding is shown in figure 43. Only the winding of the *A* phase is shown in order to avoid confusion in showing the interconnection of coils. The connections for the *B* and *C* phases are identical with those of *A*. In phase *A* the free ends of the coils have been interconnected so that the electromotive forces of all conductors are additive.

There are 48 slots in the stator. The distance between centers of adjacent field poles is 180 electrical space degrees. Since there are four poles, this corresponds to 12 stator slots and the distance between adjacent slots is 15 electrical space degrees.

The $+B$ phase belt must be displaced 120 degrees from the $+A$ phase belt. This corresponds to a displacement of eight slots from the beginning of $+A$ to the beginning of the next $+B$. Similarly the $+C$ phase belt will begin eight slots from the beginning of the $+B$ phase belt.

The interconnection of phase belts to form a three-phase *Y*-connection is shown in figure 44.

It should be understood that shipboard generators use fractional pitch as well as full-pitch windings. The advantage of a fractional-pitch winding is that it improves the wave form and results in less generator reactance. A fractional-pitch winding is illustrated in figure 45.

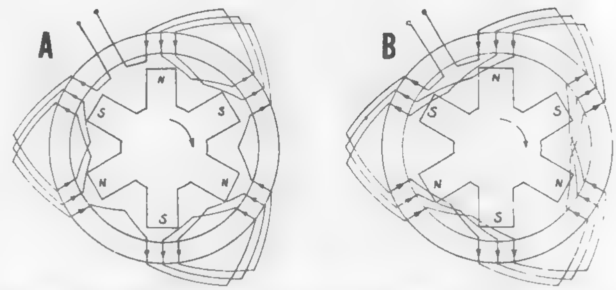


Figure 42.—Single-phase lap and wave winding—(A) Lap winding (B) wave winding.

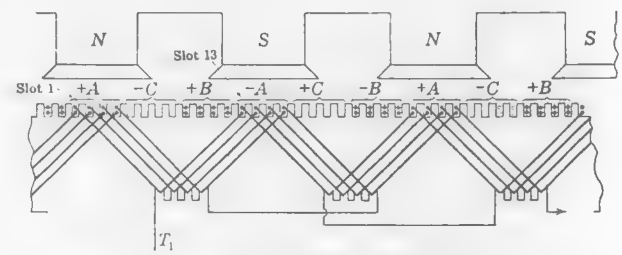


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Figure 43.—Three-phase full-pitch two-layer lap winding.

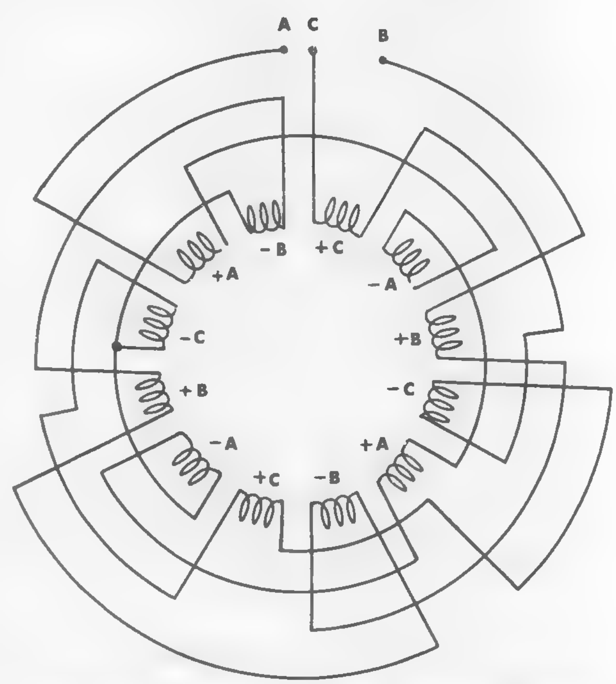
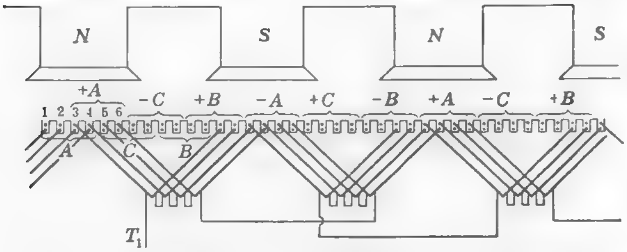


Figure 44.—Three-phase, four-pole, series-wye winding.



Courtesy of McGraw-Hill Book Co., Inc., New York, N. Y.

Figure 45.—Three-phase fractional-pitch winding.

Exciter

The general construction of exciters is similar to that described under chapter 3 for d-c generators. The magnet frame or stator is usually bolted to a sub-base extending from the base of the set. The exciter sleeve-type bearing is lubricated by an oil ring and suction feed. Oil is carried in a reservoir in the exciter bearing support.

Operation and Maintenance

PRELIMINARY INSPECTION

Before a generator is started for the first time after installation or after an extensive overhaul, a careful examination of all operating parts and electrical connections should be made as a precaution against damage to the machine or personnel. The following conditions should be satisfied before the machine can be safely started:

1. Generator and exciter connections should check with the manufacturer's diagram.
2. The air gaps of the generator and exciter should be free and unobstructed, and there should be proper clearance between all moving parts.
3. The generator collector rings should have a clean polished surface and the brush pressure should be about 2 pounds.
4. Coupling bolts should be tight.
5. All parts of the generator and the exciter should be free of foreign objects.
6. Insulation on all windings should be undamaged.
7. Generator and exciter bearings should have adequate lubrication; all oil lines to and from forced feed lubricated bearings should be free of obstructions to the flow of oil.
8. All connections should be tight.
9. Insulation resistance of all windings should be within safe limits as determined by an insulation tester or "megger."
10. The rotor assembly should turn freely when turned slowly by hand.

Starting

When the generator set is first started after installation or extensive overhaul, it should be brought up gradually to its rated speed. Considerable time should be allowed for warming up the prime mover and also for observing any undue vibration in the generator. All switches and circuit breakers controlling the exciter and generator should be open during this period.

Before applying load to a machine, the following procedure should be carried out:

1. Check the generator phase rotation. This can be done with a phase rotation meter or with a three-phase motor where the direction of rotation is known. In this latter test, motor leads T_1, T_2, and T_3 should be connected to buses A, B, and C, respectively. If the motor turns in the proper direction, the phase rotation of the generator is correct. If it turns in the wrong direction, the phase sequence is incorrect, and any two of the generator leads to the bus should be interchanged.

2. Check the flow of ventilating air to the machine and see if it corresponds to that indicated in the manufacturer's instruction book. This can be done by holding a smouldering piece of waste near the intake and observing the path of the smoke through the machine.

3. Check all bearings to be sure that there are no oil leaks and that the bearings are running at normal temperature.

4. If the machine contains an air cooler, turn on the water and examine the system for leaks.

5. Check the machine carefully for any undue vibration or noise. The machine should be shut down if such conditions are detected, and the cause determined and removed.

Application of Load

When a generator is ready to be connected to its load and is not required to operate in parallel with any other machine, the following operating procedure is performed:

1. Adjust the exciter field rheostat until the exciter voltage reaches its normal value.
2. Close the generator field switch and decrease the resistance in the generator field circuit by adjustment of the field rheostat or, in the case of a motor-operated rheostat, by adjustment of the rheostat-control switch until the generator voltage reaches its normal value. Check the exciter voltage and make any necessary adjustment to keep it at the normal value.

   When machines have variable voltage exciters, close the generator field switch and decrease the exciter field resistance until the generator voltage reaches normal value.
3. Adjust the frequency of the generator by operation of the governor-control switch. The frequency meter will serve to indicate the frequency at which the machine is operating.
4. Place the voltage regulator in service by putting the voltage-regulator transfer switch in the "Normal" or "Automatic" position. Check the generator voltage and make necessary adjustments by operation of the voltage-adjusting rheostat.
5. Close the generator circuit breaker. The bus is now energized and the load may be applied.

Synchronizing Generators for Parallel Operation

Before a-c generators can operate in parallel, they must be synchronized, as explained above in the section on "Operating Principles." On the larger vessels where there are as many as eight generators, considerable caution must be exercised to avoid closing a generator into an energized bus without first synchronizing it with the other machines tied into that bus. In the larger systems the ship's load is shifted around from one generator to another in order to obtain an approximately equal distribution of running time. Each time this is done the incoming machine must be synchronized with the connected machines before it can be closed on the bus and made ready to accept its share of the load.

The procedure for synchronizing an incoming machine with an energized bus is as follows:

1. Make adjustments on control devices of incoming machine to secure approximately normal speed and voltage, and place the voltage regulator in control as previously described.
2. Check bus voltage and generator voltage by switching the voltmeter from the bus to the generator with the voltmeter switch.
3. Turn the voltage-adjusting rheostat of the voltage regulator until the incoming-generator voltage is equal to the bus voltage.
4. Connect the synchroscope across the bus and the incoming generator by turning the synchronizing switch to the "On" position. The synchroscope will then rotate in one direction or the other, depending on the difference in bus and generator frequencies. Manipulate the governor-control switch of the incoming machine until the synchroscope is rotating very slowly in the clockwise direction. When the synchroscope pointer passes very slowly through the zero position, close the generator breaker.

Synchronizing lamps are also included on the switchboard for use in emergency when the synchroscope is inoperative. If lamps are used in place of the synchroscope, the generator breaker is closed when the lamps are dark.

Power and Reactive Load Adjustment

As shown in the discussion of parallel operation the change in power-load distribution between two generators operating in parallel is effected by adjusting the governor settings on their respective prime movers. It was also shown that a change in the distribution of reactive load could be made by changing the field excitation of one or both machines.

Under normal operation the adjustments are made on the governor-control switches and the voltage-adjusting rheostats so that there is an equal distribution of power load and reactive load among all generators operating in parallel.

When power load is shifted from one machine to another, the governor switches of both machines should be manipulated simultaneously in order to maintain constant frequency.

Reactive kilovolt-ampere is indicated by the power-factor meters or by a comparison of ammeter readings with wattmeter readings. If two

machines are operating with equal power factors, the reactive kilovolt-ampere distribution is equal. If the power-factor meter readings are different, the machine with the lowest power factor is carrying the major part of the reactive load.

When making adjustments to equalize the reactive load, the voltage-adjusting rheostats of both machines should be manipulated simultaneously in short steps in order to maintain constant voltage.

Procedure for Securing a Generator Operating Independently

1. Remove as much load from the generator as practicable by opening feeder breakers on power and lighting circuits.
2. Trip the generator circuit breaker.
3. Remove the voltage regulator from control by shifting the regulator switch to "Manual."
4. Insert the full resistance of the field rheostat in the generator field circuit by operation of the rheostat-control switch (if the rheostat is motor-operated) or the rheostat handwheel (if the rheostat is designed for manual operation).
5. Insert the full resistance of the exciter field rheostat in the exciter field circuit by operation of the rheostat handwheel.
6. Pull out the field switch slowly to open the generator field circuit.
7. Secure the prime mover in accordance with the operating instructions for the particular machine installed.
8. Shut off the water to the air-cooler if there is a cooler installed.
9. Turn on the heaters (if installed) within the generator enclosure.

Procedure for Securing a Generator Operating in Parallel

1. Shift all the load from the machine being secured to the other machines by manipulating the governor-control switches. If the total connected load is greater than the capacity of the other machines which are to continue operating, it will be necessary to decrease the total load by opening some of the feeder circuit breakers.
2. Trip the breaker of the generator being secured.
3. Secure the generator and prime mover as outlined under "Procedure for Securing a Generator Operating Independently," items 3 through 9.

Maintenance

Inspection.—Generators and exciters should be inspected at regular intervals. These inspections should include insulation tests of all windings, and observation of general cleanliness of the machines, and condition of collector rings, brushes, exciter commutator, and clearances between rotating and stationary parts. In the course of inspections the machines should be blown out with low-pressure compressed air to remove loose dirt or lint. All connections should be cleaned of oil and dirt.

Collector rings.—Collector rings should be given careful attention in order to preserve highly polished surfaces and their true cylindrical shape necessary for satisfactory operation. Brushes should be checked regularly to see that they are free to move up and down in the brush holders. When brushes show signs of appreciable scoring due to hard particles being imbedded in their contact surfaces, they should be resanded in accordance with similar procedures used on d-c machine brushes.

When a machine is idle for an appreciable length of time, pitting of the collector rings may occur where the brushes rest on the ring surfaces. This is due to electrolysis between the brushes and rings and is particularly apt to happen when the generator is exposed to moist, salty air. To prevent this action, the brushes should be raised off the rings during such periods of shut-down.

When severe pitting occurs the rings must be turned and a cut taken. The depth of the cut will depend on the depth of the pitting. Rings should then be polished to a mirrorlike finish by rotating them at high speed and polishing them with a piece of crocus cloth. Light pitting can be corrected by dressing the rings with sandpaper and then polishing with crocus cloth.

When brushes chatter, it is probably because of irregularities on the ring surfaces. If chatter is allowed to continue for any prolonged period of time, it may cause chipping of the brushes. It can be corrected by the removal of ring pitting as outlined above.

Collector rings should be kept free from a coating or scaling of any kind by cleaning periodically with carbon tetrachloride or a similar solvent.

Generator stator and rotor windings.—With the exception of keeping windings free of foreign objects

and in a clean condition very little maintenance is usually required. Inspections will reveal any appreciable damage to insulation, which should be corrected in severe cases by replacement of coils. Minor damage may be repaired by impregnating the damaged area with insulating compound and by thoroughly drying out.

If generator windings have absorbed moisture by standing idle in an atmosphere of high humidity, they should be dried out before being placed in operation again. Insulation which has absorbed moisture suffers a reduction in dielectric strength and may break down when the machine is operated at its normal voltage. Megohmmeter tests should be frequently applied to an idle generator, and if the machine is clean, a low insulation reading will generally be an indication that the insulation has absorbed an excessive amount of moisture. Dirt in windings can also affect the insulation strength, as indicated by the insulation tester.

There are three methods of drying out a-c generators. One method is to pass direct current through the windings with the machine at standstill. This is done in the armature circuit by connecting the direct current supply across the *A* and *B* terminals for a few hours and then changing successively to the *B* and *C* and *C* and *A* terminals. As the drying progresses, the connections are changed periodically to heat the winding uniformly. The field winding is then energized with direct current by clamping copper bands to the collector rings and connecting these to the direct current supply. The current should never be allowed to pass through the brushes, since local heating would occur under the brushes and cause blackening of the rings and possible damage to the brushes.

The amount of current to be applied to the armature is approximately full-load current as determined from the generator name plate. The current applied to the field can be full-rated field current.

The second method for drying out windings is to use alternating current. This is done by short-circuiting the main terminals and driving the machine at reduced speed. The field current under these conditions should be only enough to cause the desired armature current to flow in the winding. Normal-rated armature current should not be exceeded during the drying-out process.

The third method of drying out windings is to use external heat. Generally a shore job, application of external heat is resorted to when windings have become soaked because of flooding. This method necessitates the use of an oven or a number of coils of steam pipe passed through or around the windings.

The exciter field winding may be dried out by the use of direct current, as described above for the a-c generator. The armature may be dried either by the use of external heat or by operation on short circuit. When the armature is dried under short-circuit conditions, the shunt and the series field windings should be opened. Sufficient current will be generated with the residual magnetism of the field. The heated air thrown off by the rotating armature will usually be sufficient to dry out the field.

Exciter commutator and brushes.—Maintenance of the exciter commutator and brushes follows the procedures as outlined for d-c generators in chapter 3.

Disassembly and assembly of generator and exciter during extensive overhaul.—The disassembly and assembly of generators and exciters for repairs or for overhaul should be carried out in accordance with the detailed procedures as outlined in the manufacturers' instruction books.

VOLTAGE FLUCTUATION

The importance of maintaining a substantially constant voltage at the generator bus has been demonstrated by the effects of large voltage fluctuations on the operation of various electrical equipment. These effects are associated with steady state voltage changes owing to the gradual increase or decrease in load and large transient voltage disturbances owing to sudden load changes.

Light Flicker

The sudden voltage dips associated with the starting of an induction-motor or other load surges produces flicker in the lighting system. If this flicker is of sufficient magnitude and frequency it will cause considerable annoyance to the ship's crew and impair operation of the vessel.

Effect on Magnetic Devices

Contactors, relays, and similar electromagnetic devices depend for correct operation on an applied voltage that does not drop below certain limits under steady state and transient conditions. These devices are generally returned to their open position by a spring, and when the voltage drops, the

force exerted on the armature by the electromagnet is increasingly offset by the force of the spring. When the drop-out voltage of the device is reached, the armature is moved by the spring. This motion takes place at a rate depending on the inertia of the armature and the degree of undervoltage. Under some transient conditions, the voltage recovery is fast enough to keep the magnetic devices from opening. The voltage recovery after the starting of an induction-motor, however, has been found. to be too slow to prevent relay and contactor opening. For this reason the voltage drop at induction-motor starting should never be allowed to go below drop-out values.

Effect on Motor Operation

Voltage fluctuations affect practically all of the characteristics of an induction motor, but the effects on torque and rise of temperature are most significant. The torque varies directly as the square of the applied voltage and the rise of temperature varies inversely with the voltage to a degree dependent on the ratio of copper to iron losses in the particular motor. In general the increased rise of temperature does not become excessive unless the voltage is considerably below the normal value (10 per cent or more).

Induction motors and their connected loads have relatively little inertia and depend almost entirely on the continued application of torque to maintain speed. Experience has shown that transient voltage dips can cause sufficient reduction in torque to stall the motor. For this reason, the maximum torque of a motor is greater than that of the load to allow a suitable margin for operation at reduced voltages under transient as well as steady state conditions. Conversely, the system voltage regulation must be so designed that it does not require this margin to become excessively large. Normally the maximum motor torque is at least 200 per cent of rated torque; therefore, the applied voltage should in no case be less than 70 per cent of normal.

CHAPTER 5

VOLTAGE REGULATORS

General

VOLTAGE REGULATION IN THE A-C SYSTEM

Up to the time of adoption of the a-c system for naval combat vessels, the provision for satisfactory voltage regulation was a minor problem. The inherently good voltage regulation of direct-current generators, low-starting currents of d-c motors, and the relatively small effect of voltage disturbances on the operation of electric auxiliaries combined to provide systems substantially free of voltage-regulation difficulties.

A-c generators on the other hand introduced large inherent voltage-regulation characteristics which were unsatisfactory for the proper operation of electrical equipment. This necessitated the use of voltage regulators that would automatically respond to voltage changes and act to increase or decrease the generator field excitation accordingly. Shipboard voltage regulators must be simple in construction, resistant to shock, and quick in response to transient voltage disturbances.

Types of Voltage Regulators

The majority of voltage regulators in service on naval vessels today are of two types. These are the direct-acting rheostatic type and the indirect-acting rheostatic type.

The *direct-acting rheostatic type*, sometimes known as the variable resistor type, has a voltage-sensitive element in the form of a solenoid, magnetic torque element, or torque motor that exerts a mechanical force directly on a variable resistor in the generator or exciter field circuit.

The *indirect-acting rheostatic type* of voltage regulator has a voltage sensitive element that controls both a motor-operated rheostat for changing field resistance and relays that cut large blocks of resistance into, or out of, the field circuit. The large blocks of resistance are quickly removed or inserted in the field circuit when the voltage variations are such as to require considerable correction. The sensitive element operates the motor-operated rheostat for small voltage changes and for final adjustment after operation of the relays.

Another step in the accomplishment of better voltage regulation has been realized in the development of the rotary-amplifier voltage regulator. Not only does this type of regulator respond more quickly to transient voltage disturbances, but its inherent design eliminates the need for moving parts, arcing contacts, and delicate mechanisms characteristic of the other types.

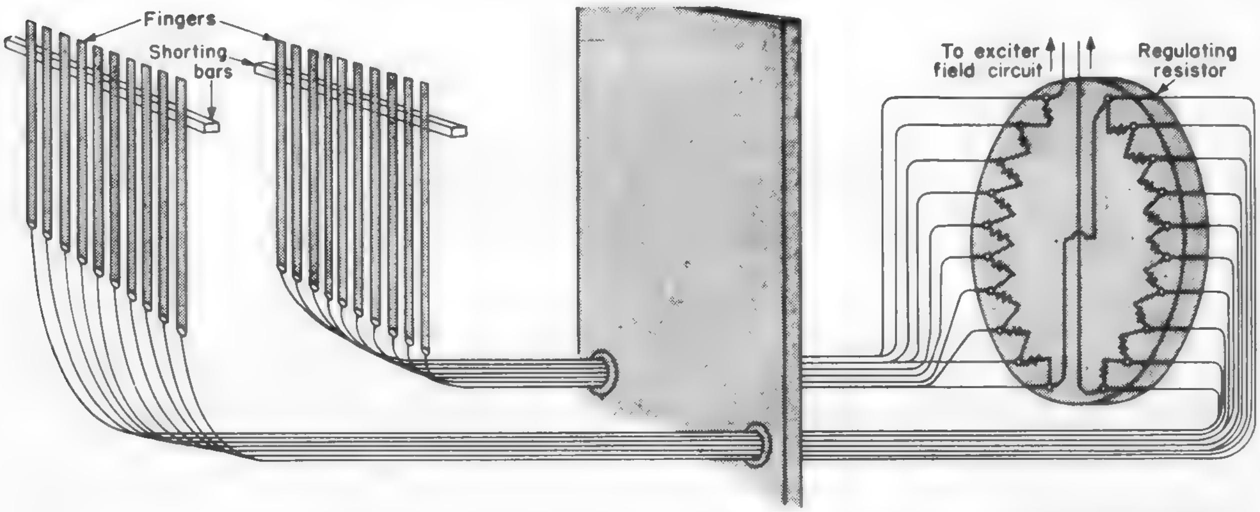
The rotary-amplifier voltage regulator makes use of a special d-c generator with an output that is an amplification of the input to its control field. It differs from an ordinary exciter in that the response to a change in field current is much more rapid.

Direct Rheostatic Type Regulator

One of the more typ cal direct-acting regulators has a resistor with many taps connected to fingers which operate in conjunction with silver shorting bars to vary the exciter field resistance. A schematic diagram of this arrangement is shown in figure 46.

The fingers are raised from, or lowered to, silver connecting bars by a fiber shape similar to that shown in figure 47.

The fiber shape is an integral part of the armature of an electromagnet shown in figure 48 and varies its position as the strength of the magnet



Courtesy of General Electric Co.

Figure 46.—Schematic diagram of direct rheostatic-type regulator.

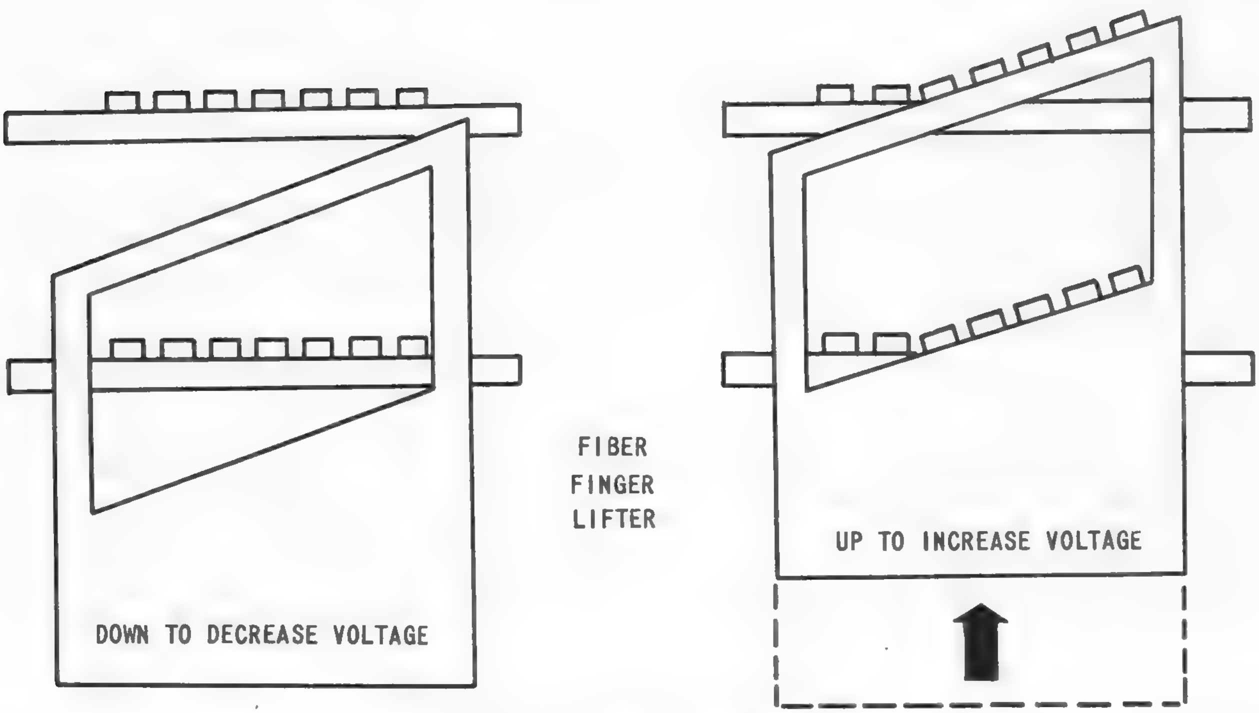
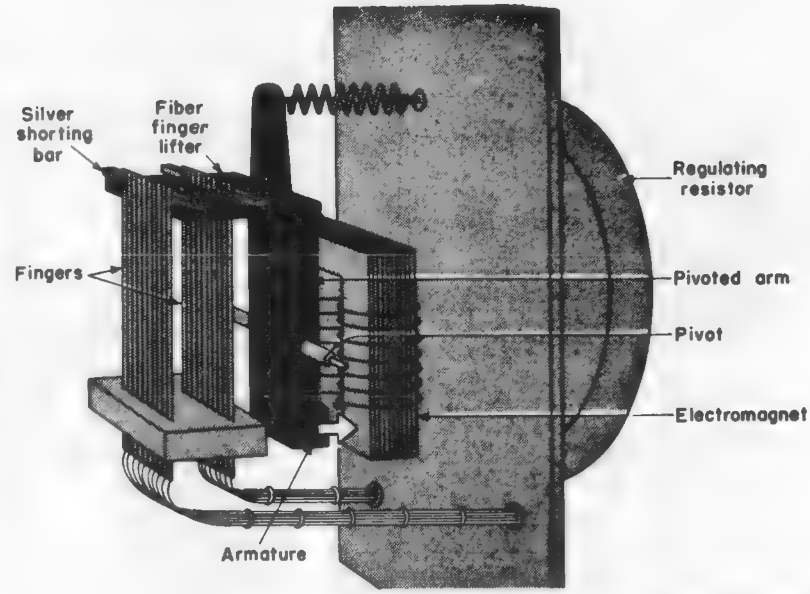


Figure 47.—Operation of resistor fingers.

is increased or decreased. The magnet coil is connected through a rectifier and potential transformer to the generator bus and therefore responds to variations of generator voltage.

As the generator voltage decreases, the armature moves in the direction of spring pull and an increasing number of fingers are connected to the silver bars until a balanced condition between spring force and magnet force is reached. As more and more fingers are connected, resistance is shorted out of the exciter field circuit and the generator field excitation is increased to supply the necessary

An increase in voltage on the windings of the electromagnet attracts the armature, which moves the fiber finger lifter attached to the pivoted arm, in such a direction as to raise some of the contact fingers from the shorting bars.



Courtesy of General Electric Co.

Figure 48.—Voltage-control element.

corrective effect for return of generator voltage to its original value.

Similarly a rise in generator voltage causes the fingers to be disconnected from the silver bars with a resultant increase in exciter field resistance and a corrective effect in decreased generator field current for return of generator voltage to its original value.

The main connections between the regulator, the exciter field, and the line, are given in figure 49.

In addition to the function of maintaining a substantially constant generator voltage, voltage regulators are required to maintain a reasonable division of reactive-kilovolt-ampere between two or more machines operating in parallel. The division of kilowatt load between generators is adjusted by the prime mover governors.

To provide for proper division of reactive kilovolt-ampere, this type of regulator makes use of a paralleling circuit consisting of a current transformer and an equalizing reactor.

When two machines are operating with equal division of kilowatt load and one machine tends to take more than its share of the reactive current, the equalizing reactors will change the excitation applied to the individual generators so that the power factors of the two machines will be nearly equal.

The voltage-adjusting rheostat connected into one of the a-c input lines to the rectifier as shown in figure 49, is the means of adjusting the level of the regulated a-c generator voltage.

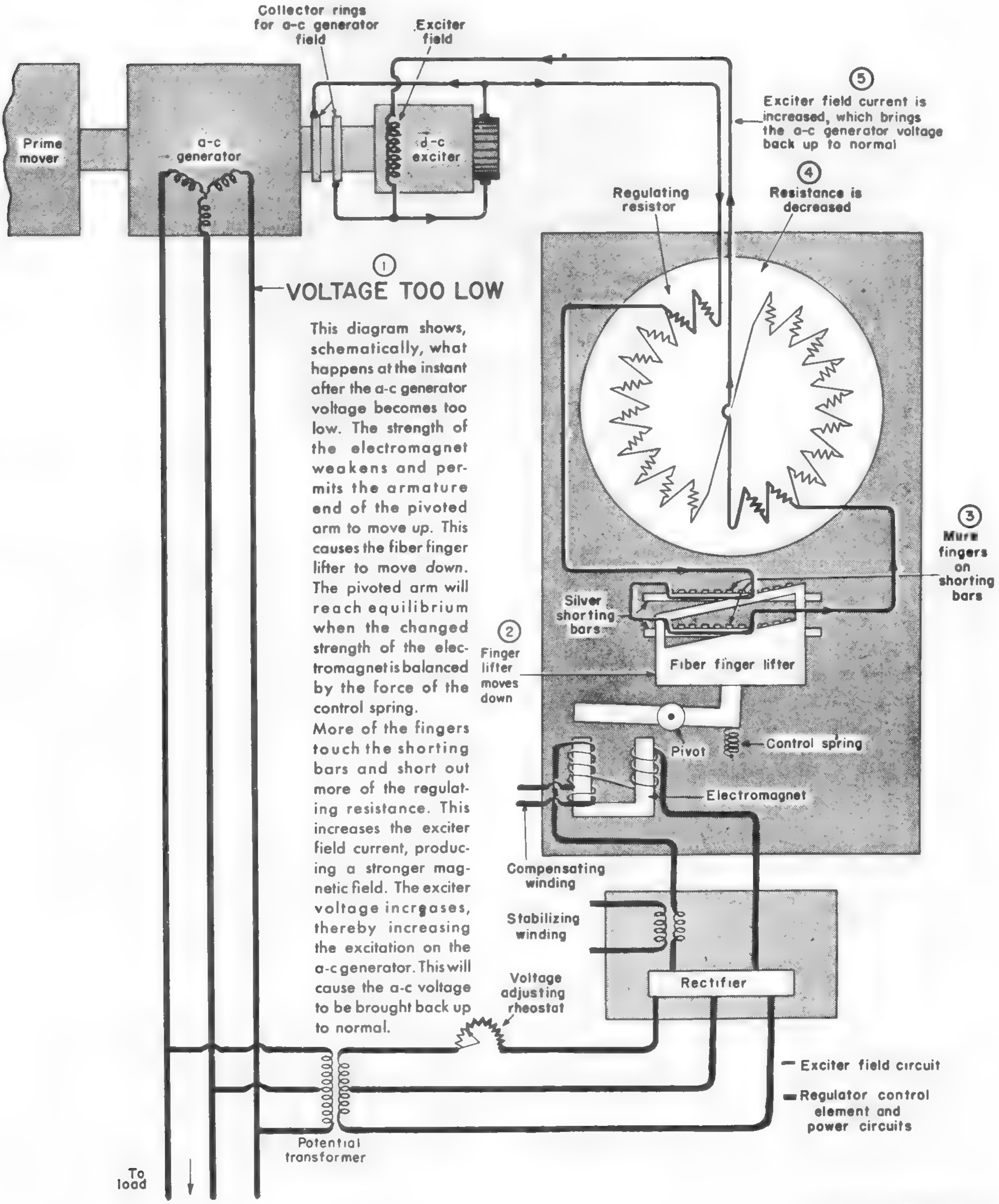
Indirect Rheostatic Type Regulator

The indirect rheostatic regulator installed on most ships of the Navy operates in conjunction with a motor-operated rheostat which is connected in the generator field circuit. The voltage-sensitive element of the regulator is a three-phase torque motor that has two pairs of contacts attached to its armature as shown in figure 50.

The torque-motor windings are connected to the generator bus through potential transformers. Since the torque-motor is energized from all three phases, its torque is proportional to the approximate average three-phase voltage.

Between the two pairs of contacts are two continuously rotating contact wheels, one front and one rear, with which the spring contacts make and break. These contact wheels are driven by a telechron motor connected to a 110-volt a-c supply.

At normal voltage the motor torque is balanced



This diagram shows, schematically, what happens at the instant after the a-c generator voltage becomes too low. The strength of the electromagnet weakens and permits the armature end of the pivoted arm to move up. This causes the fiber finger lifter to move down. The pivoted arm will reach equilibrium when the changed strength of the electromagnet is balanced by the force of the control spring.

More of the fingers touch the shorting bars and short out more of the regulating resistance. This increases the exciter field current, producing a stronger magnetic field. The exciter voltage increases, thereby increasing the excitation on the a-c generator. This will cause the a-c voltage to be brought back up to normal.

Courtesy of General Electric Co.

Figure 49.—Schematic diagram of connections.

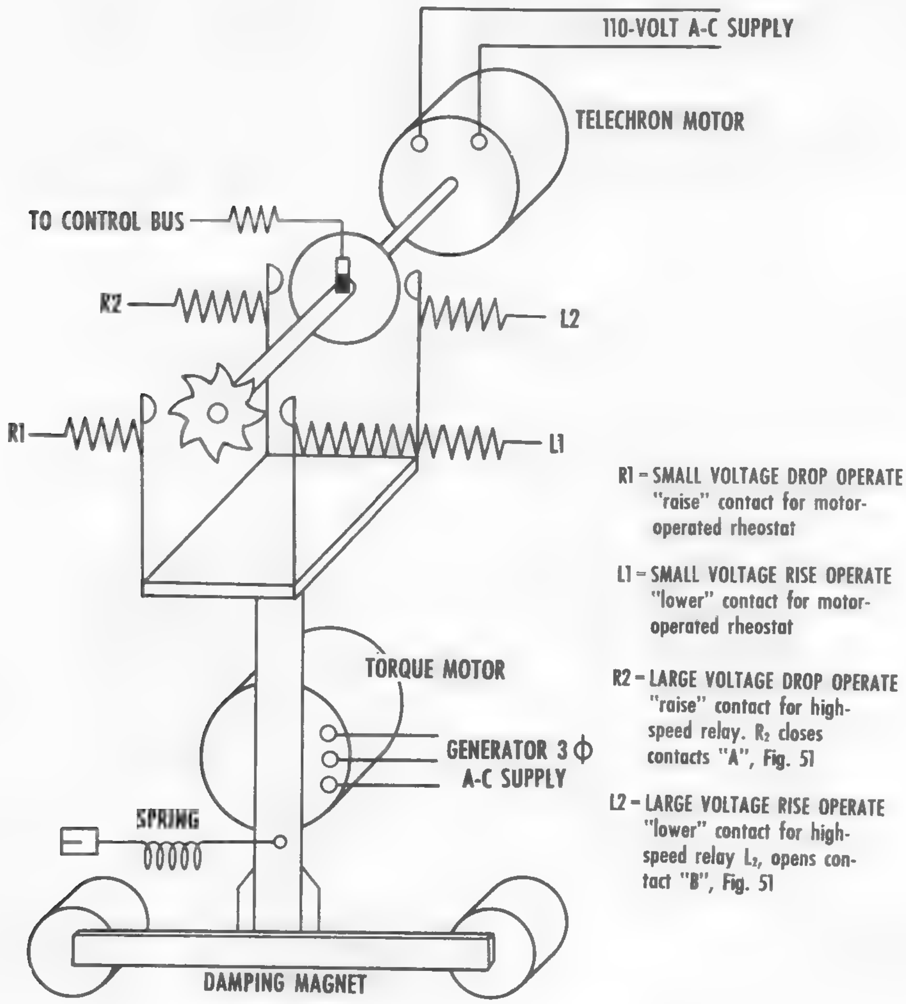


Figure 50.—Voltage-sensitive element.

by a spring. When the generator voltage increases beyond that value, the torque motor turns its shaft counterclockwise until its torque is balanced by that of the spring. Conversely, when there is a drop in generator voltage, there is a decrease in motor torque and the shaft is pulled in a clockwise direction by the force of the spring until a balanced condition is reached.

The torque motor in the process of rotating its attached contact assembly first closes a front contact (L_1 or R_1) with the notched rotating wheel. These contacts are wired into the rheostat motor circuit so that when L_1 closes, the motor operates the rheostat to lower the generator voltage and when R_1 closes, the motor operates the rheostat to raise the generator voltage.

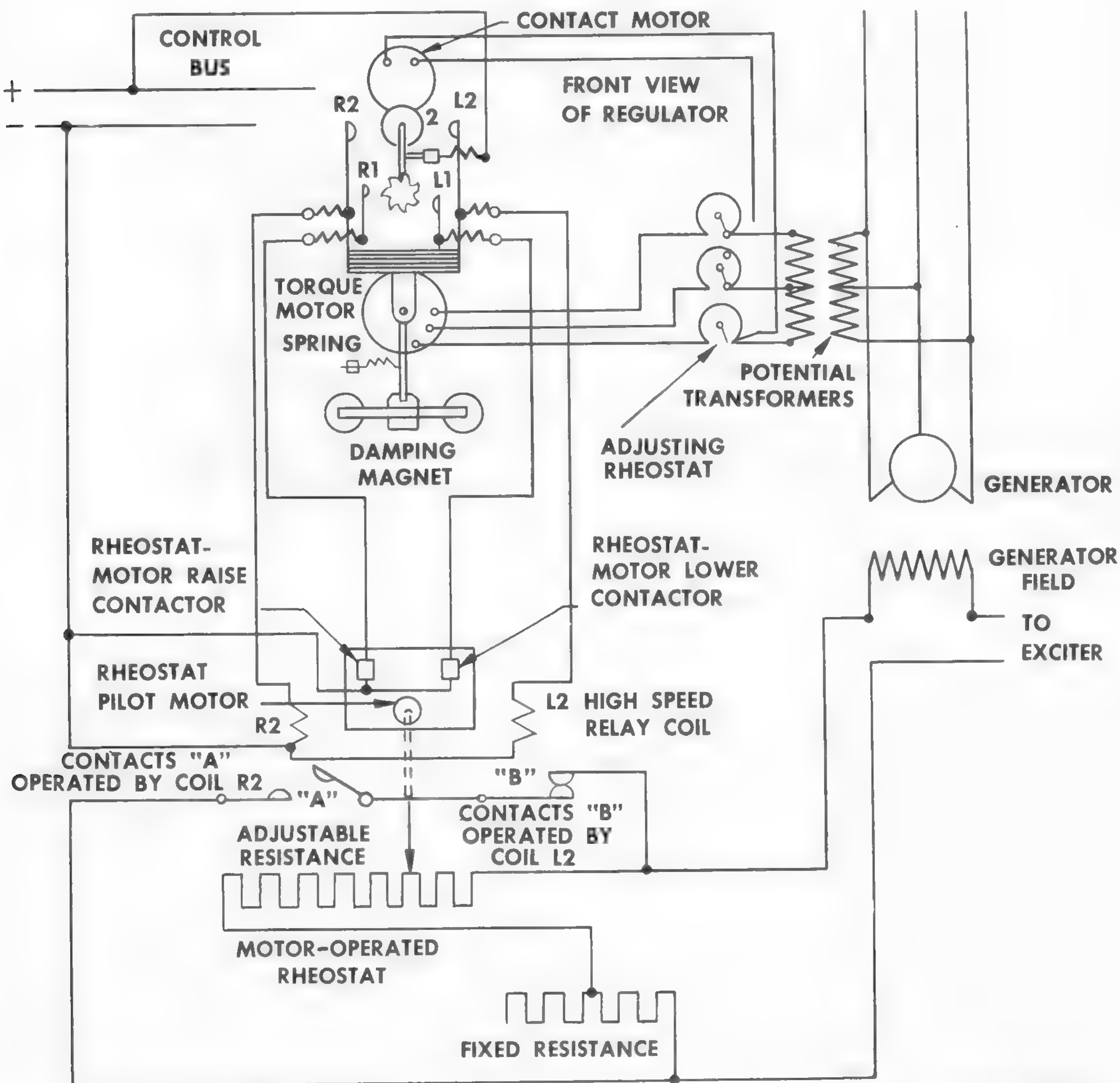
The front wheel is notch-shaped; hence, when the voltage changes are slight, the L_1 or R_1 contact engages only the high points of the wheel, and the circuit to the rheostat motor is closed and opened intermittently. The rheostat-adjustment mechanism is thus moved in short steps, with the length of each step dependent on the degree of voltage correction required.

With voltage changes of greater magnitude, the L_1 or R_1 contact engages the notched wheel for a longer time, permitting the rheostat to travel more quickly to its required position. If the voltage change is large enough, a front contact will engage the notched wheel continuously and one of the back contacts (L_2 or R_2) will engage the smooth wheel. Observe in figure 51 that when the contact L_2

engages the smooth wheel, a circuit is closed to the solenoid of relay L_2 which opens a contact "*B*" to insert the fixed resistance *FR* into the generator field circuit.

If, on the other hand, the R_2 contact engages the wheel, a circuit is closed to the solenoid of relay R_2 which closes its contact *A* and shorts out the rheostat resistance. In this way a high-speed response to large voltage changes is made.

As soon as the generator has responded to the quick action of relay L_2 or R_2 by decreasing or increasing its voltage, the torque-motor contact assembly returns to a more central position and the front contacts in conjunction with the notched



Courtesy of General Electric Co.

Figure 51.—Elementary connection diagram of typical indirect rheostatic type regulator.

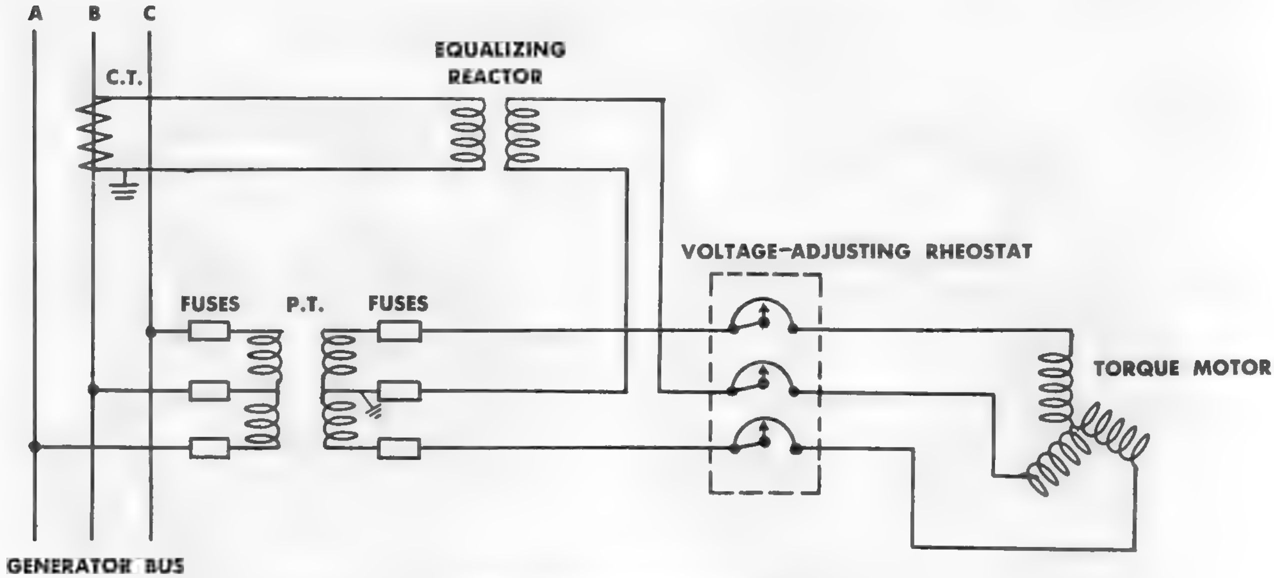


Figure 52.—Cross-current compensation.

wheel and motor-operated rheostat make the final adjustment to normal voltage.

PARALLEL OPERATION

To prevent one machine from taking all the reactive kilovolt-ampere when operating in parallel with another machine, a current transformer and an equalizing reactor, connected as shown in figure 52, are provided for each generator. The equalizer reactor applies a voltage in one phase of the torque motor which is in quadrature with the line current. At unity power factor this voltage is in quadrature with the line voltage, but as the power factor lags it becomes more nearly in phase with the line voltage and therefore is more effective in changing the voltage as supplied to the sensitive element of the regulator.

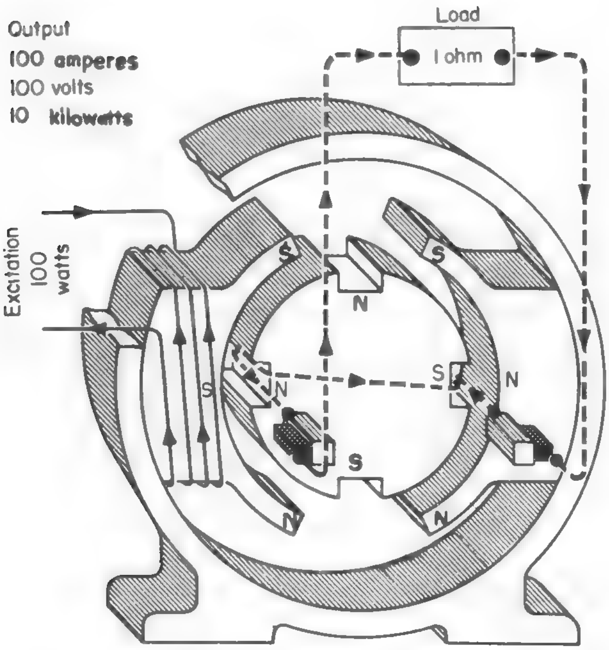
If all the machines are operating at the same power factor, these voltages due to load current are in approximately the same phase relationship and affect all regulators alike. However, if one machine tends to carry more than its share of the reactive kilovolt-ampere the additional voltage produced by the line current and the equalizing reactor swings more in phase with the line voltage, and the regulator responds to reduce the excitation on this machine until its power factor has been equalized with that of other machines.

The remaining parts of this voltage regulator circuit include the devices for manual control of generator voltage, for transfer from one regulator to a stand-by regulator and for various limit switches and interlocks. For purposes of this text these devices do not require any description.

Rotary Amplifier Regulation

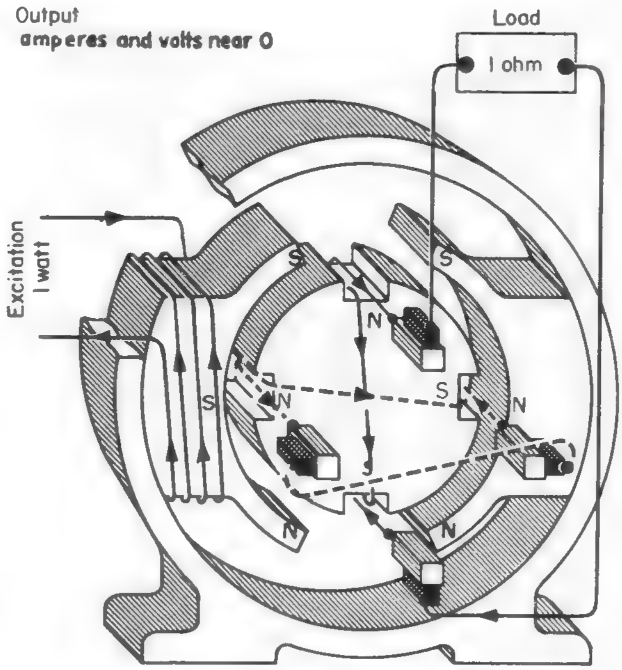
The rotary amplifier or amplidyne regulator employs a specially connected d-c exciter that produces a wide range of output through a small range of field excitation. The sensitivity of field control in this type of exciter when employed to regulate voltage permits a system of direct control from generator voltage that eliminates the intermediate field resistances and controlling mechanisms characteristics of other types of regulators. The rotary amplifier with its static-control devices for voltage regulation is not only a better performer in its quicker response to generator voltage variations' but also a compact equipment which reduces maintenance to a minimum and is generally adaptable to the shockproof requirements of naval ships.

If, as shown in figure 53, the brushes of a d-c generator are short-circuited, large values of armature current may be produced with only a small



Courtesy of General Electric Co.

Figure 53.—Two-pole d-c generator with short-circuited brushes.



Courtesy of General Electric Co.

Figure 54.—Connections for rotary-amplifier exciter.

amount of field excitation. This current flowing through the armature conductors sets up a strong magnetic field which is at right angles to the main field flux. In the ordinary generator this field is associated with armature reaction, but with the rotary amplifier exciter it serves the useful purpose of being the major source of excitation. To accomplish this, a second set of brushes is added at right angles to the first pair, forming two circuits through a single-armature winding and producing the equivalent of two windings.

As shown in Figure 54 the winding in line with the field poles cuts through that magnetic field to generate the current necessary to set up the strong armature magnetic field as indicated. The winding at right angles to the field poles similarly cuts through the strong armature magnetic field and produces at the corresponding brushes a voltage that is approximately the same as a conventional d-c generator with full field excitation.

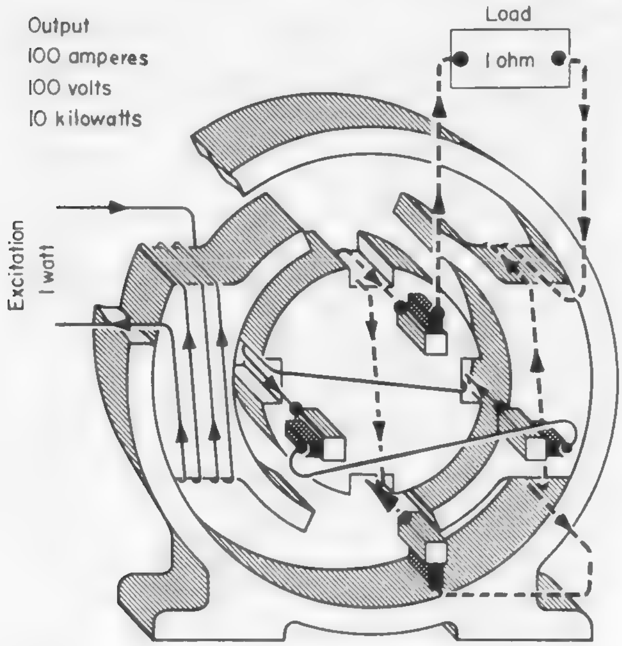
When current flows in this circuit, which is the case when a load is connected between the brushes, a new armature field is set up that is opposed to the one produced by the field poles. If allowed to persist it would cancel out the greater part of the effect of the original exciting current. To correct for this armature field, a compensating field winding is added which is excited by the load current, as shown in figure 55. The magnetizing effect of this field cancels the armature field produced by the lead current and the full effect of the exciting current is restored.

Thus the rotary amplifier is able to amplify a comparatively weak field pole excitation into a strong armature field that is utilized as a main field to generate the field current for the a-c generator.

Some idea of this amplification is illustrated in the comparison of field excitations between a conventional generator and a rotary amplifier of the same kilowatt output. A conventional d-c generator rated at 10 kilowatt will usually require about 100 watts excitation, or about 1/100 of the output, whereas a 10-kilowatt rotary amplifier requires only 1 watt, or 1/10,000 of the output.

The amplification of the rotary amplifier is further increased with the addition of a series field. This field provides most of the excitation to produce the armature short-circuit current; thus it decreases the amount of current in the control field necessary to produce a given voltage and current output.

The automatic control circuit that operates in conjunction with the rotary amplifier as a voltage



Courtesy of General Electric Co.

Figure 55.—Connections for compensating field winding.

regulator is designed to respond to slight changes in the a-c generator voltage and provide the amplifier control field with an excitation which either bucks or boosts the series field, depending on whether the generator voltage is high or low with respect to normal voltage.

The heart of this circuit, a saturated reactor, is nothing more than a coil wound around an iron core. The characteristics of a saturated reactor can be seen from examination of the typical saturation curve of figure 56.

With the reactor excited by voltages on the steep portion of the curve, small changes in voltage have little or no effect on the change in current output. On that portion of the curve above the knee, however, the effect of small voltage changes on current output is considerable. This characteristic is effectively used as a voltage-sensitive element in a regulator circuit. Taps are provided on the coil of the reactor for changing the voltage at which the reactor operates on the regulating portion of the curve. A tap switch therefore serves the same purpose as a voltage-adjusting rheostat with other types of regulators.

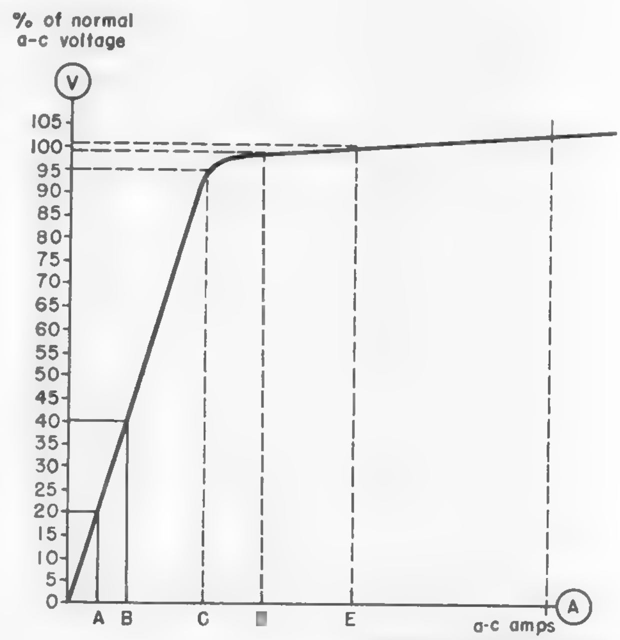
In the fundamental regulator circuit, shown in figure 57, the output of a reactor connected to one phase of the generator supply is combined with the output of a pilot alternator to provide a buck or boost input to the amplifier-control field.

The pilot alternator is a small permanent magnet-excited rotating field a-c generator mounted on the extension of the amplifier shaft. It develops a voltage proportional to the speed of the generator set, and, since the generator set is governed to maintain the speed necessary to produce 60-cycle voltage in the generator, the effective a-c voltage developed at the terminals of the pilot alternator will be essentially constant.

The outputs of both the saturated reactor and the pilot alternator are rectified to d-c current by selenium cell rectifiers to provide a d-c supply to the control field.

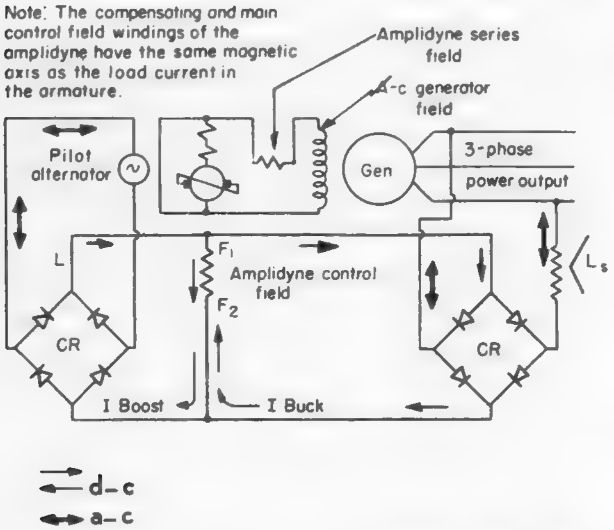
Notice in figure 57 that the current supplied to the control field is the difference between the output of the reactor and the pilot alternator. When the pilot alternator current is in excess of that supplied by the reactor, the circuit operates to boost the field. Conversely, when the reactor current is in excess of that supplied by the pilot alternator, the circuit operates to buck the field.

When the generator is operating at normal voltage, the reactor current is practically equal to that of the pilot alternator and the current through the



Courtesy of General Electric Co.

Figure 56.—Saturated-reactor characteristic curve.



Courtesy of General Electric Co.

Figure 57.—Fundamental voltage-regulator circuit, not frequency compensated.

control field is negligible. Under this condition the excitation for the amplifier is produced almost entirely by the series field and the amplifier is not effective in raising or lowering the generator voltage.

With a drop in generator voltage, however, there is a decrease in reactor current with a net result that a boosting current is supplied to the control field. A rise in generator voltage will on the other hand cause a rise in reactor-output current so that a buck current is supplied to the field.

The circuit illustrated in figure 57 is incomplete since it responds to only one of the three-phase output voltages of the generator and does not compensate for slight changes in frequency above and below 60 cycles per second. Furthermore, the complete equipment must provide reactive compensation for proper division of reactive load between generators operating in parallel, equipment for manual control of voltage and a stabilizing device to restrain the regulator from making excessive exciter-voltage correction.

Since the purpose of this part of the text is to describe only the basic operation of rotary amplifier regulators, a description of these additional elements is not included. Details of their operation are available in manufacturers' instruction books.

Maintenance and Trouble Shooting

The maintenance procedures prescribed in manufacturers' instruction books for voltage regulators are comparable to those for various switchboard and motor-control devices, particularly if the equipment is either a direct or indirect rheostatic type. With these types, great importance is attached to the smoothness and cleanliness of contacts on switches, relays, and the voltage sensitive elements. It is also emphasized that the moving parts of these devices be free in their operation with no tendency to stick or move sluggishly.

A frequent cause of trouble is loose connections. It is generally recommended that all connections be checked once each month for tightness. Grounds in the various devices can also be troublesome and all circuits should be checked monthly with a megger for grounds.

Most ships carry an ample supply of regulator spare parts from which can be drawn the necessary part of a device or the device itself to make repairs in the shortest possible time. No attempt is made to repair resistors, reactors, control transformers, coils and the like when these parts burn out. Contacts are renewed when it appears that the contacts in service cannot be smoothed out without impairing their effective contact surface.

Efficiency in locating and correcting trouble in a regulator circuit is generally a measure of the repairman's understanding of regulator operation. The close observation of a regulator's response to voltage disturbances when the equipment is functioning perfectly is a base line for detecting faulty operation. This, combined with a knowledge of each device and its individual function, greatly simplifies the process of locating the trouble and taking the necessary steps toward replacement of parts, adjustments, and repairs.

When trouble develops which is not readily apparent in the operation of moving parts, the tightness of connections should be immediately checked. Having eliminated the possibility of loose connections, the nature of the trouble will generally indicate that part of the circuit which is not functioning properly. Static devices, such as resistors,

reactors, transformers, and capacitors, are then tested individually in accordance with manufacturers' instructions to see if they are burned out, grounded, or in any other way not operating as designed. These tests are carried out with ohmmeters, meggers, voltage testers, and any other instruments required for these purposes.

INDIRECT RHEOSTATIC-TYPE REGULATORS

Voltage regulators of the indirect rheostatic type probably require more attention than any other type. The voltage-sensitive element depends on a fine adjustment of its balance spring for correct functioning of its contacts with the rotating wheels. With the generator operating at normal voltage or the voltage corresponding to the setting of the voltage-adjusting rheostat, the contact arm must be in a position where the contacts are exactly centered with respect to the rotating wheels. Adjustment to obtain this condition is made by changing the tension of the balance spring.

When the regulated voltage with this type of regulator becomes erratic or unstable, the clearance of the regulator contacts with the rotating wheels should be checked. Manufacturers' instruction books specify that percentage of normal voltage at which the contacts should engage the rotating wheel and from these values the clearance adjustments can be made.

Other faults to be looked for, when improper operation of the voltage-sensitive element occurs, include binding or excessive friction in the torque-motor armature and rubbing of the damping armature on the pole faces.

In case of voltage hunting, the operation of the motor-operated rheostat should be checked for smoothness and all contact plungers on the operating arm of the rheostat should be examined to make sure that they are free and making good contact with the contact buttons. Along with this phase of trouble shooting, the a-c voltage change per button should be measured. This change should not be outside the limits for which the regulator contacts are set.

One other source of trouble, not always apparent, is a faulty contact in the voltage-adjusting rheostat. Obviously a poor connection here or anywhere in the a-c potential circuit would cause the voltage-sensitive element to make false corrections in generator voltage.

DIRECT RHEOSTATIC TYPE REGULATORS

When erratic a-c voltage conditions occur with the direct-acting rheostatic regulator, the trouble may lie in binding or friction in the pivoted arm of the regulator-control element, steps in the regulating resistor open circuited or burned out or one or more fingers not making contact with the shorting bar. The operation of the voltage-sensitive element and the contact fingers can be checked with an ohmmeter by observing the change in resistance as the various taps of the regulating resistor are cut in and out when operating the voltage-adjusting rheostat over its full range. The regulating resistor is disconnected from the exciter field circuit for purposes of this test.

ROTARY AMPLIFIER TYPE REGULATOR

While trouble is less apt to occur with the rotary amplifier regulator than with other types, it is sometimes more difficult to locate because of the more complex control circuits.

To facilitate the location of trouble, some manufacturers have provided in their instruction books, a trouble-shooting chart listing a variety of faulty operating conditions that might occur together with probable causes and remedies. Furthermore, a chart for location of defective parts is also provided which describes in detail the test procedures to be performed on individual devices.

Since the regulator depends for its operation on the interaction of a buck and boost circuit to the exciter control field, a persisting high-voltage condition is generally indicative of trouble in the buck circuit. A persisting low-voltage condition on the other hand is generally indicative of a defective boost circuit or trouble in the exciter control-field circuit.

Elimination of the automatic control unit as a source of trouble is usually the case when the performance of the regulator is the same with either normal or stand-by units.

If under these conditions, normal voltage is obtained with manual operation, the trouble is most likely due to an opening in the control-field circuit caused by improper closing of the transfer-switch contacts in the "auto" position.

The pilot alternator furnishes the boost current in both the manual and automatic-control circuits.

A persisting low-voltage condition for both manual and automatic control may therefore be caused by faulty operation of the pilot alternator itself or its associated boost circuit.

It is evident from the above that a preliminary diagnosis can be made by utilizing the transfer switches provided for shifting from normal to stand-by automatic control or from automatic to manual control.

From this diagnosis, that component section of the control circuit which is giving trouble can usually be found, and the individual defective device or devices located by applying the tests as prescribed by the manufacturer.

CHAPTER 6

POWER SWITCHBOARDS

Generator and Distribution Switchboards

FUNCTIONS OF POWER SWITCHBOARDS

The generator and distribution switchboard is truly the nerve center of any electrical system or part of an electrical system which it serves. The entire generated power of a ship's plant is routed through switchboards for proper protection and control before being distributed to the various power consuming equipment.

The major functions of generator and distribution switchboards are outlined as follows:

1. To provide circuit protection for associated generators and distribution feeders.
2. To control the operation of associated generators.
3. To control through appropriate switching equipment the distribution of electric power.
4. To indicate with suitable measuring instruments, indicating lights, mechanical targets, etc., the operating conditions of generators and selected distribution circuits.

Switchboard Equipment

Generator and distribution switchboards include the following major items of equipment:

1. *Circuit breakers* for connecting, disconnecting, and protecting of generators, bus ties, and distribution feeders.

2. *Indicating instruments* such as voltmeters ammeters, wattmeters, frequency meters, power-factor meters, and synchroscopes.

Ammeters are ordinarily provided to indicate the load current of each generator. Voltmeters are arranged to indicate generator voltage and bus voltage. *Wattmeters*, *frequency meters*, and *power-factor meters* are furnished for each generator in an a-c installation. A synchroscope is provided for each a-c switchboard for the purpose of paralleling a-c generators.

3. *Indicating lamps* to indicate circuit-breaker position for generator, bus tie, and other important circuits, power available at certain power sources, and power failure.

4. *Synchronizing lamps* are provided as an alternate means of synchronizing a-c generators when there is a failure of the synchroscope. Ground detector lamps are used to detect grounds in a distribution system.

5. *Field rheostats* for d-c generator field circuits and a-c generator exciter field circuits. Hand-operated rheostats are mounted on switchboard panels with the operating handwheel on the front of the board. Motor-operated rheostats, sometimes used on large a-c installations in the generator field circuit, are unusally mounted on the deck behind the switchboard and are controlled from a switch mounted on the generator control panel. An operating rod is extended from the rheostat to a handwheel on the front of the panel for manual operation.

6. The major control devices used with *voltage-regulating equipment* are panel mounted on the switchboard. There are several types of regulators employed on naval ships today and the amount of equipment found on the switchboard depends upon the type used. The previous chapter has briefly outlined the subject of voltage regulators.

7. *Switchboard control switches* are provided for operating motor-operated rheostats, circuit breakers, and prime mover governors. They are used as transfer switches in conjunction with voltmeters, ammeters, temperature meters, and frequency

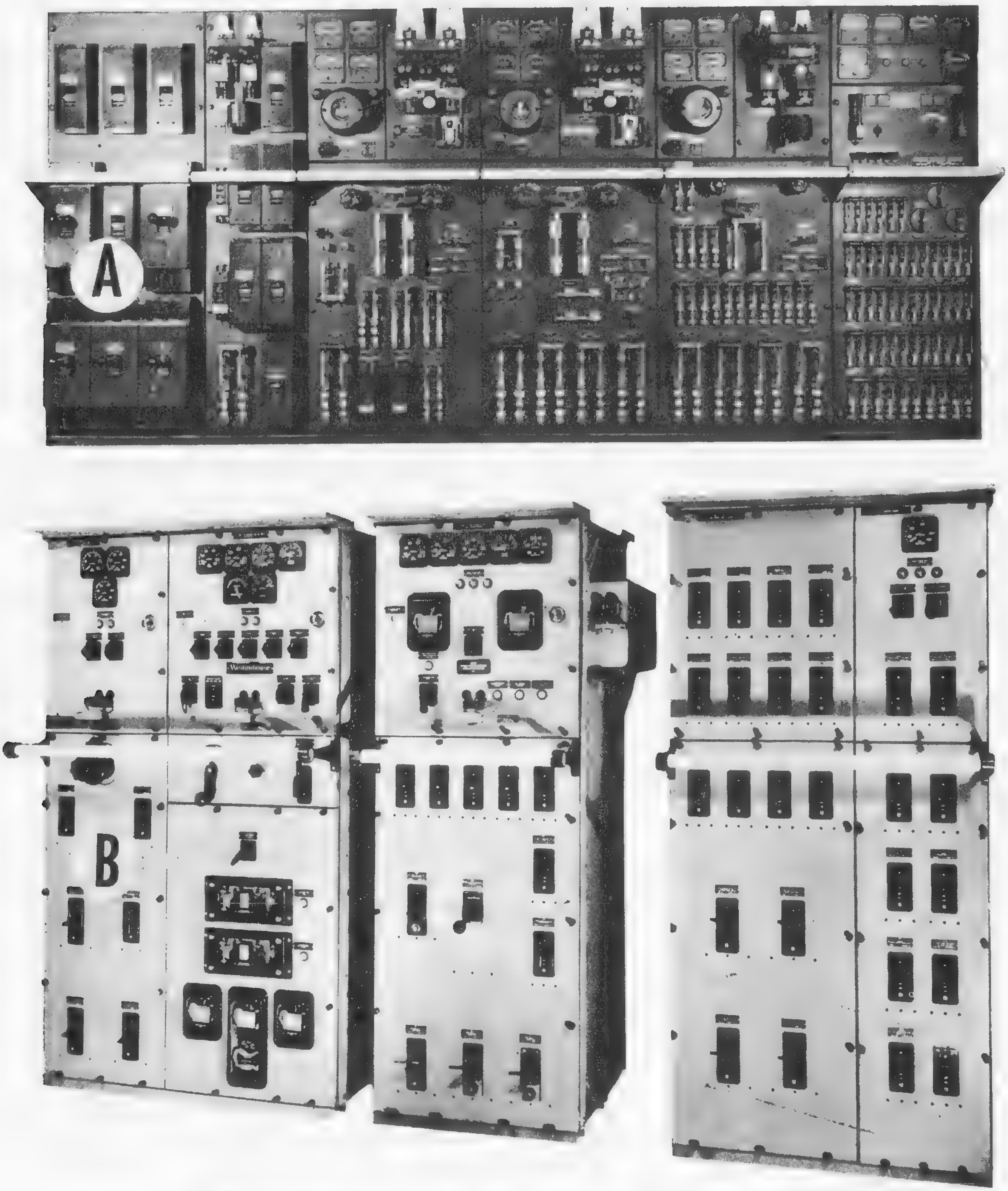
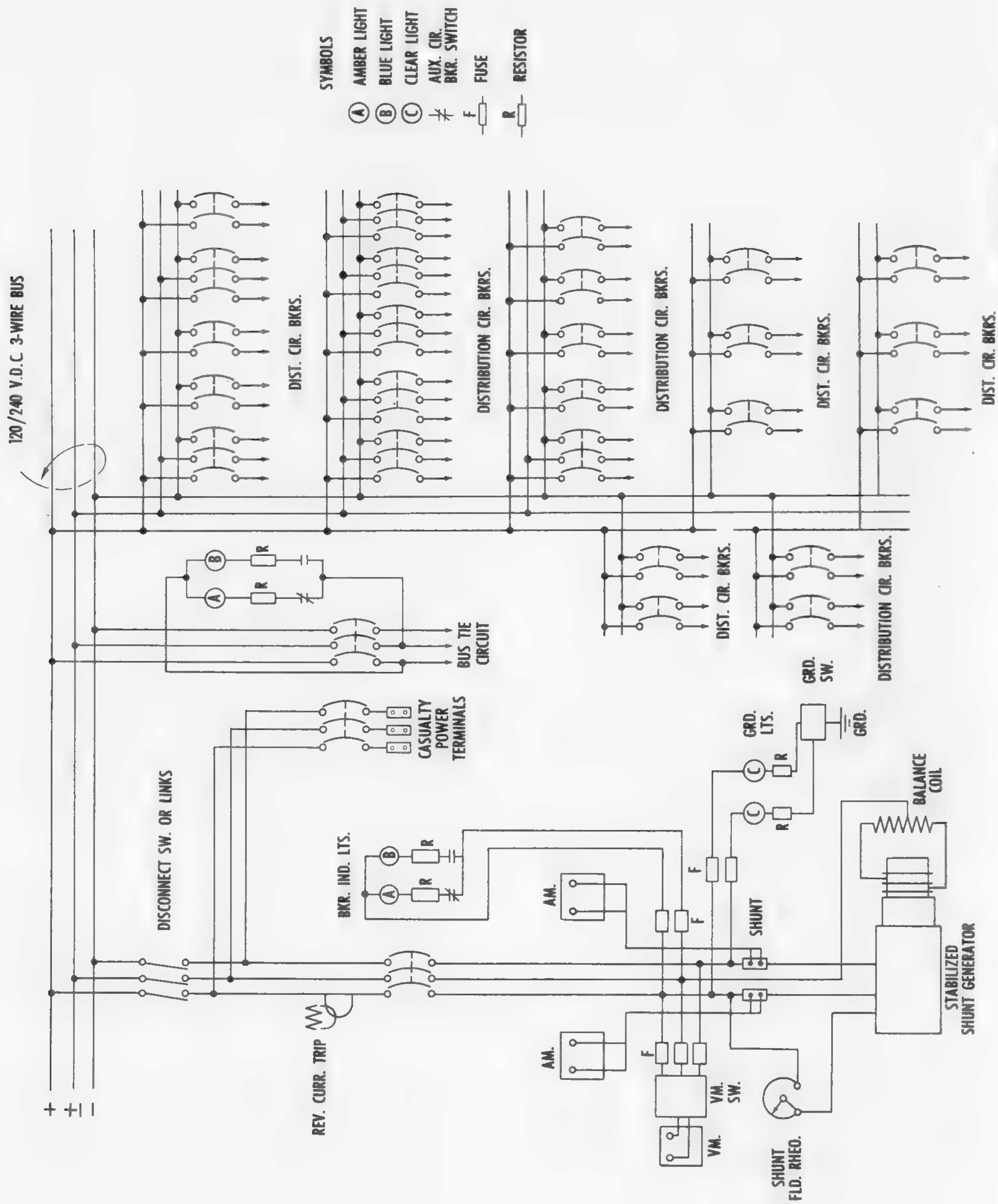


Figure 58.—Ship's service switchboards. (A) Live front. (B) Dead front.



Courtesy of General Electric Co.

Figure 59.—Schematic wiring diagram of d-c switchboard.

meters for selecting different circuits in which these instruments are used. On certain voltage-regulator installations a control switch is provided for selecting one of two regulators and for selecting either manual or regulator operation. Synchroscopes and ground-detector lights are provided with control switches for putting this equipment in service.

Construction

The advent of higher voltage application on naval ships has brought about added precautionary measures with respect to exposure of personnel to live parts in the electrical system. These measures have been exemplified in switchboard design by a transition from live-front to dead-front boards on all installations where the voltage exceeds 120 volts.

The equipment of a live-front switchboard is mounted on insulated panels and usually includes fused-type knife switches, and circuit breakers with live parts exposed. On smaller vessels with 120-volt distribution this type of construction is still considered acceptable. Furthermore with small loads in the distribution system, the fused knife switch is an acceptable means of switching and protecting distribution circuits of low capacity.

Dead-front switchboards, however, are found in the majority of applications since the increased electrical demands on even the smaller ships have necessitated the use of higher voltages. This type of construction utilizes sheet-steel panels through which only meters and operating handles protrude to the front of the switchboard. Instead of fused knife switches such as are used on live-front boards for distribution circuits, dead-front boards usually employ enclosed-type circuit breakers.

The general appearance of live-front and dead-front construction is shown in figure 58.

Both types of construction make use of a sturdy box framework built of steel angles and structural shapes to provide strength to resist breakage and distortion as a result of shock, and stiffness to prevent excessive vibration.

While the long box-frame assembly was more typical of switchboards built for naval vessels during the war, the present trend in construction is toward splitting the switchboard into several independent self-supporting sections with interconnecting cables between them. This type of design has been predicated on battle damage reports which have revealed the weaknesses of long structural switchboard assemblies in their ability to withstand shock and hull distortion. Furthermore with all generator, bus tie, and feeder circuit breakers connected to one long bus which cannot be sectionalized, experience has shown that damage at any one point can render the entire switchboard inoperable.

The equipment of each unit in a switchgear group is housed in a sheet-steel enclosure with the necessary frame supports. Access to equipment is through hinged doors or removable panels at the front or rear. On large vessels the control is centralized in a separate unit and is similarly enclosed with sheet-steel panels and structural frame supports.

Direct Current Ship's Service Switchboards

Although a-c power has supplanted the older d-c ship's service systems on combat ships, there is still a wide use of d-c for ship's service power on auxiliary vessels.

Because of its limitation to auxiliary vessels, d-c distribution is ordinarily not required to maintain the high degrees of reliability required on combat ships. The degree of reliability is, however, carried out within the limits of practicability, being guided by the operating conditions for which the vessel is designed, its size, and the vulnerability of its overall construction to the effects of battle damage.

An outstanding feature of reliability in power distribution on combat ships is the installation of two or more independently operated ship's service switchboards with associated generators and the location of this equipment in different parts of the vessel. On the other hand, auxiliary vessels generally rely on a single switchboard and associated generators located in the main engine room or an adjacent auxiliary-machinery space.

D-C SWITCHBOARD CONNECTIONS

The schematic diagram of connections for a typical generator and distribution switchboard shown in figure 59 illustrates the following features of control and protection:

1. Generators are connected to the power dis-

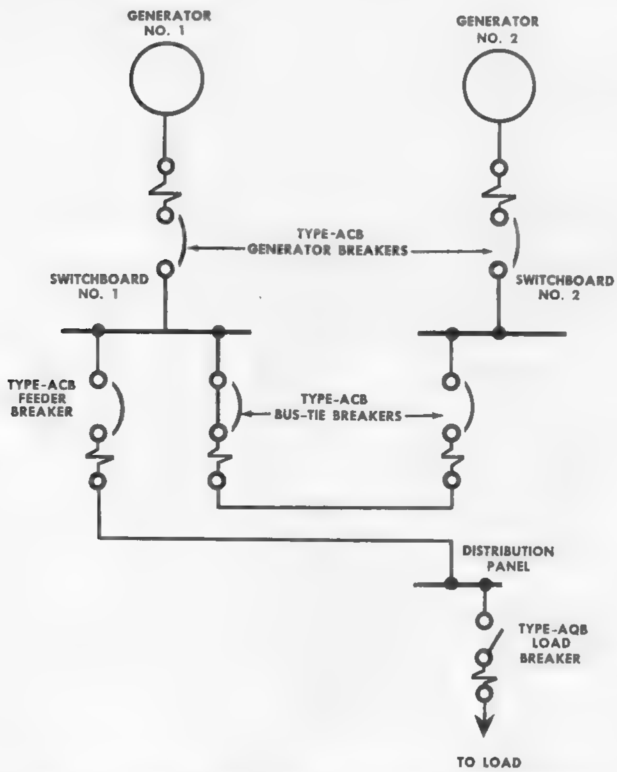


Figure 60.—Special ship's service switchboard bus arrangement to provide circuit breaker back-up protection.

tribution system through circuit breakers which are designed to automatically disconnect them from the bus under predetermined conditions of overload or short circuit.

2. Reverse current trips integral with the circuit breaker protect the generators against motoring when operating in parallel.

3. Disconnecting switches permit the circuit breakers to be isolated from the bus for service and repair.

4. Circuit breakers with automatic tripping devices are provided on all distribution circuits to isolate circuit faults.

5. Voltmeters are connected through selector switches to measure generator and bus voltages.

6. Two ammeters are provided with three-wire generators to measure the current in the positive and negative leads. These ammeters are connected into the line through suitable shunts.

7. Generator field rheostats are connected in series with the shunt field circuits for purposes of adjusting generator voltage.

8. Indicating devices include circuit breaker indicating lights and ground-detector lights.

Ship's service switchboards on the larger vessels contain many more distribution circuits than shown in figure 59. The feeder breakers are grouped in accordance with size and the load which they serve. Where there is a large lighting load, a segregation between lighting and power is made by including separate buses and separate panels.

Circuit breakers are sometimes used to provide back-up protection for feeder circuit breakers in applications where the available short circuit current exceeds feeder breaker interrupting capacities and it is undesirable to use too many of the larger breakers because of space limitations. Back-up circuit breaker protection is illustrated in the diagram of figure 60.

Feeder breakers to machinery space ventilation panels on the larger auxiliary ships are provided with shunt trips operated from push-button stations outside the machinery spaces. This feature is included as an aid to the control of fires in the machinery spaces.

Alternating Current Ship's Service Switchboards

It is not within the scope of this book to cover in any detail the various types of a-c switchboard equipment now used aboard naval vessels. Therefore, a brief description of the component parts of a single switchgear group on a representative large combat ship will serve as a suitable introduction to manufacturer's instruction books which describe a particular installation in detail.

CONTROL BENCHBOARD

A separate control section is provided in the switchgear groups of battleships, cruisers, and aircraft carriers. This section is called a control benchboard.

The control benchboard mounts all generator-control equipment, all measuring instruments, and

Courtesy of General Electric Co.

Figure 61.—Control benchboard.

all control equipment for electrically operated systems. It thus provides an operating station with centralized control of generators and major switching operations. A typical control benchboard is shown in figure 61.

Generator Control Unit, Bus Tie Unit, and Distribution Section

In switchgear groups, the circuit breaker and disconnecting switches for a ship's service generator are mounted in a separate metal-clad cubicle equipped with hinged panels for access to the equipment. This cubicle also houses the current and potential transformers for generator instruments and control power.

The circuit breaker and disconnect switches for each bus tie are mounted in separate cubicles which are of similar construction to the generator cubicle. Current and potential transformers for bus tie instruments and circuit breaker control power are also contained in these cubicles.

The distribution part of a ship's service switchgear group is divided into two sections, with the total number of feeder circuit breakers being divided between the two sections. The circuit breakers are of the draw-out type to facilitate their inspection and maintenance. The draw-out frames are so made that the breakers must be in the open position before they can be racked in or out of the units, thereby preventing the operator from removing a breaker-carrying current or inserting a closed breaker into a live circuit.

Generator and bus-tie circuit breakers are electrically operated and are controlled by switches on the control benchboard. An operating handle is provided at each cubicle for manual closing of the breaker in the event that there is a failure in the electrical closing devices. There is also a combination manual tripping and hold-in device at each cubicle that can be used to open the breaker when the electrical control fails to operate and which serves as a means of holding in the breaker to prevent opening under any conditions.

The cable interconnections between generators and bus-tie circuit breaker cubicles and the distribution sections are illustrated in figure 62. Circuit breaker cubicles and distribution sections are shown in figure 63.

Emergency Switchboards

Emergency switchboards on the combat ships are designed with special automatic control to perform the following functions:

1. To transfer the emergency bus from a normal ship's service supply to an alternate ship's service supply when there is a power failure on the normal supply.

2. To start the Diesel engine automatically and transfer the connected load to its generator when there is a power failure on both normal and alternate ship's service supplies.

3. To remove all connected load from the emergency generator, except the steering gear, when the total load exceeds the setting of an overload relay. This applies to the after emergency switchboard.

An additional facility is provided with bus feeders between forward and after emergency switchboards. Thus, when there is a failure of power on both ship's service feeders to an emergency switchboard and the local emergency generator cannot be operated, the emergency bus may be energized through a bus feeder from the remote emergency generator to serve certain selected loads. This is accomplished with manually operated switches.

The schematic diagram of figure 64 shows the various buses and switching arrangements for a single emergency switchboard.

The automatic bus transfer for normal and alternate feeders includes contactors 540 and 541. The bus transfer for ship's service and emergency power includes contactors 538 and 539. Contactor 534 is opened by an overload relay when the load on the emergency bus becomes excessive, thereby disconnecting all loads except the steering gear.

Circuit breakers 542 and 543 are manually operated and serve to connect the power and lighting bus of unit 7 to either the local or remote emergency bus. Circuit breakers 550, 551, 548, and 549 are manually operated and are used to select either the local or remote bus for two of the larger vital loads.

Control switches are provided for bus-transfer contactors and the Diesel-starting circuits as follows:

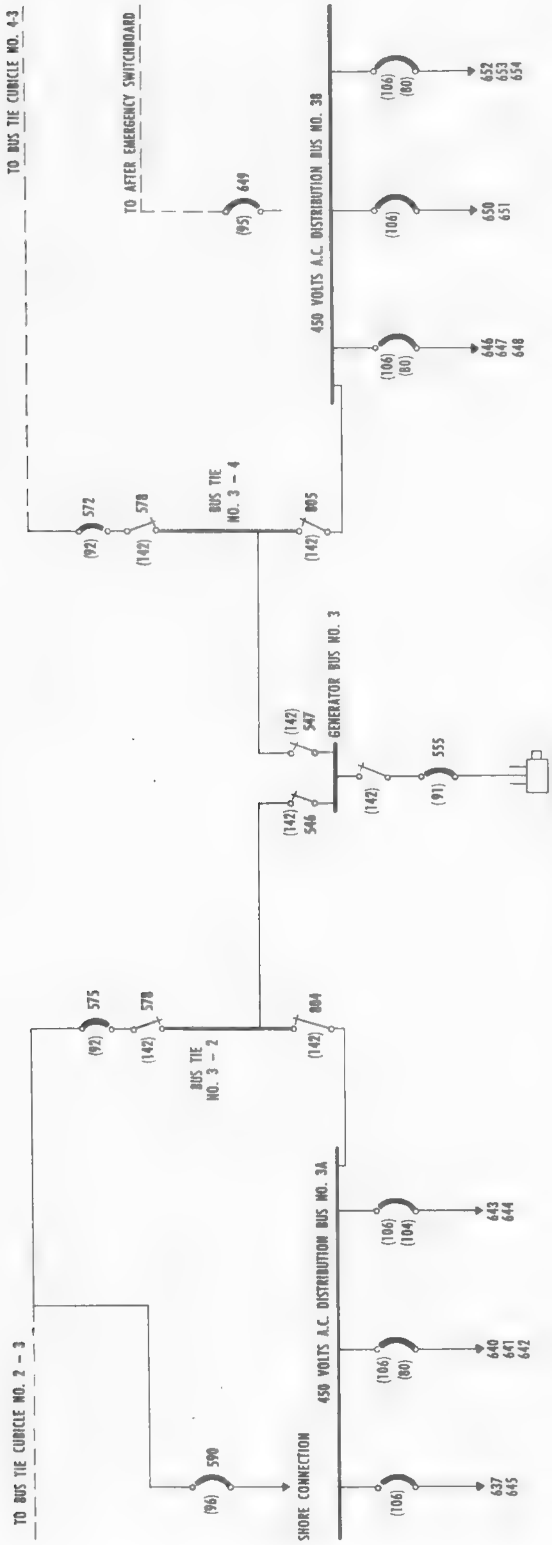


Figure 62.—Schematic diagram of ship's service switchgear group.

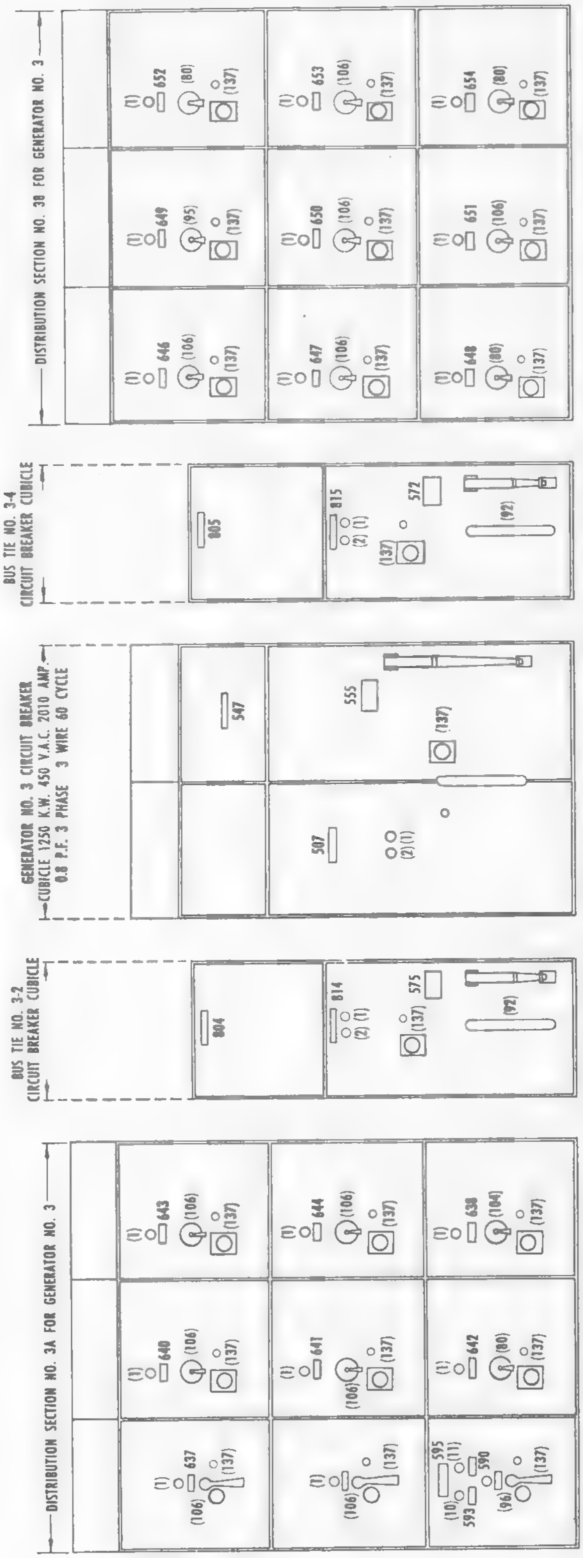


Figure 63.—Circuit breaker cubicles and distribution section (front view).

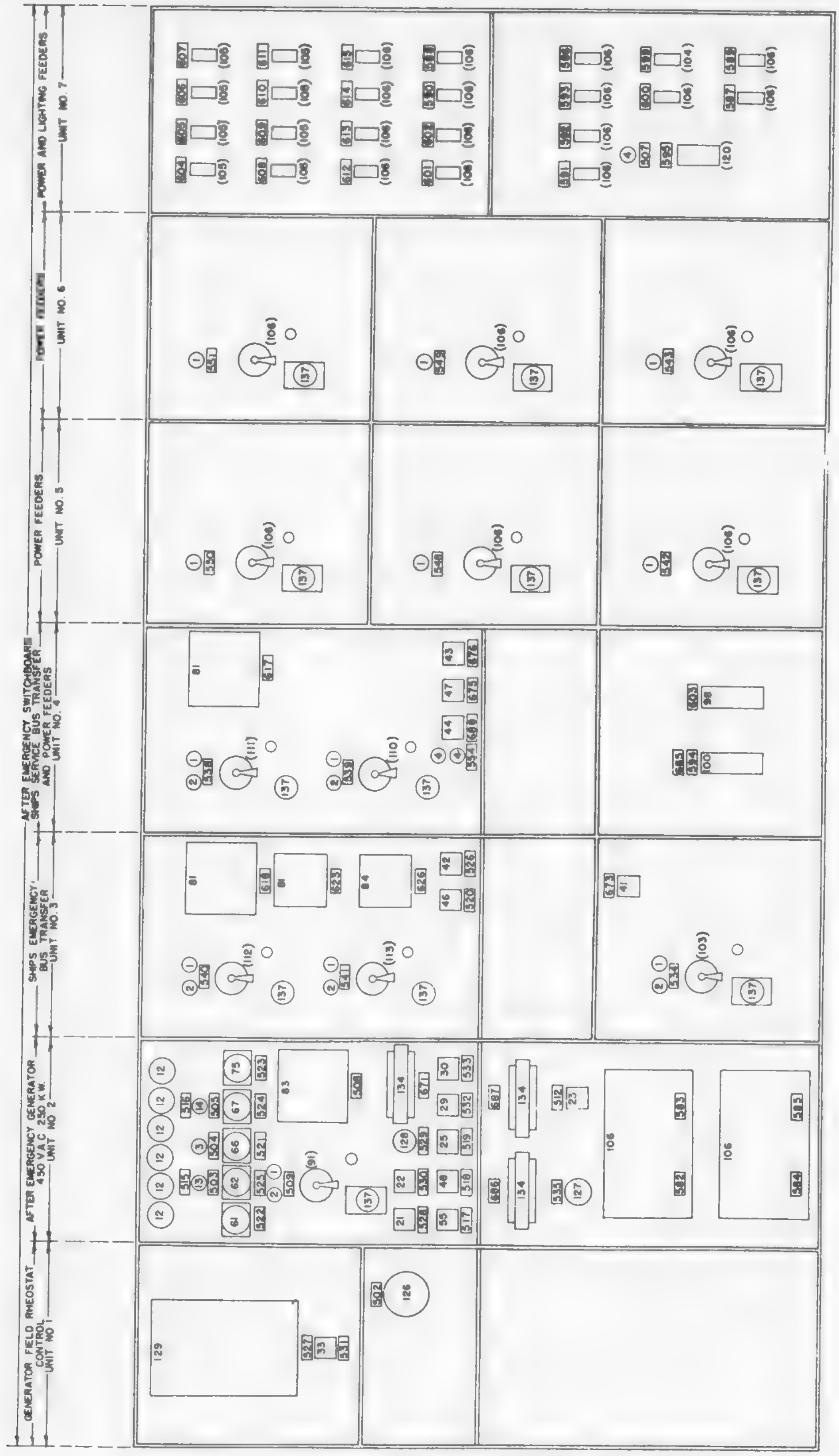


Figure 64a.—Emergency switchboard.

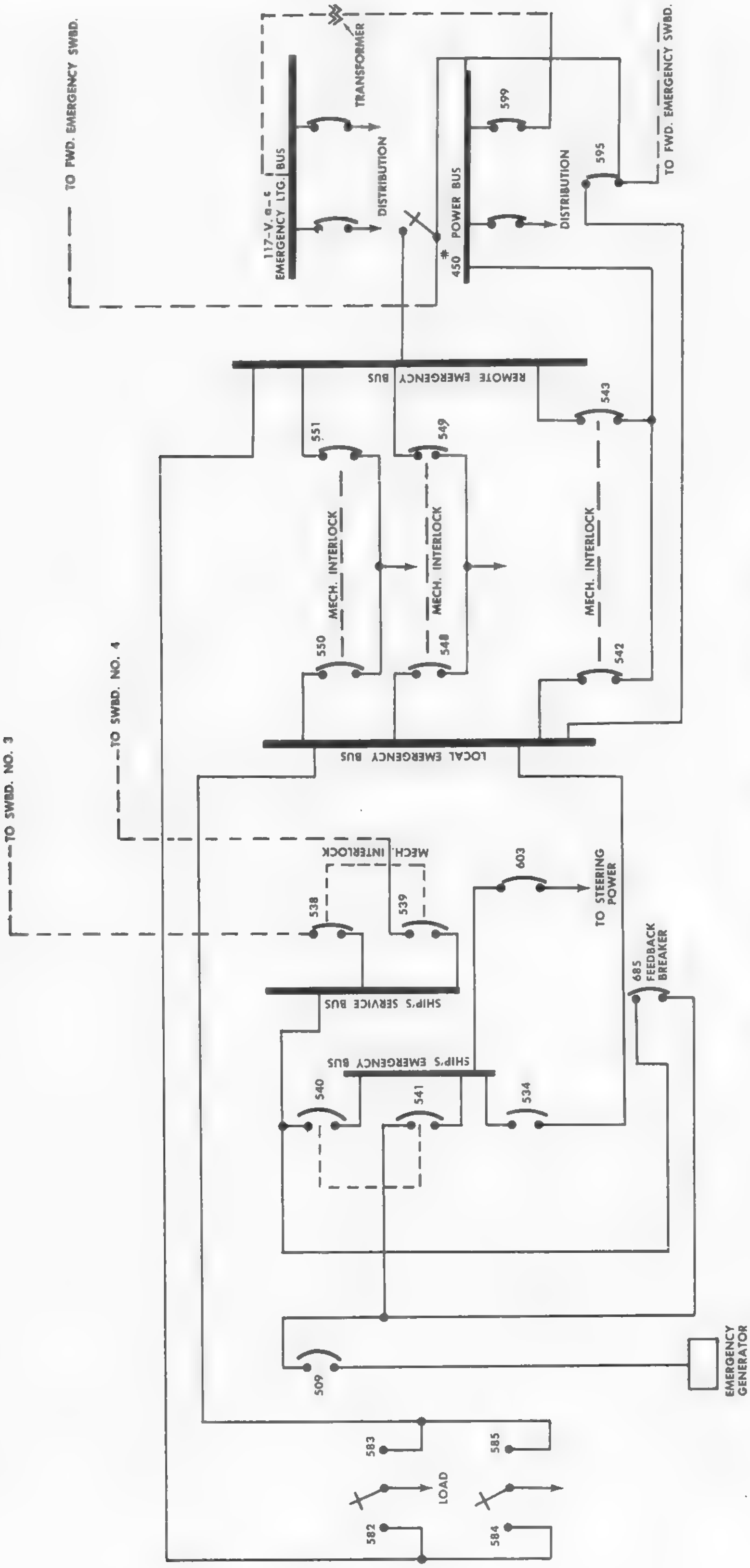
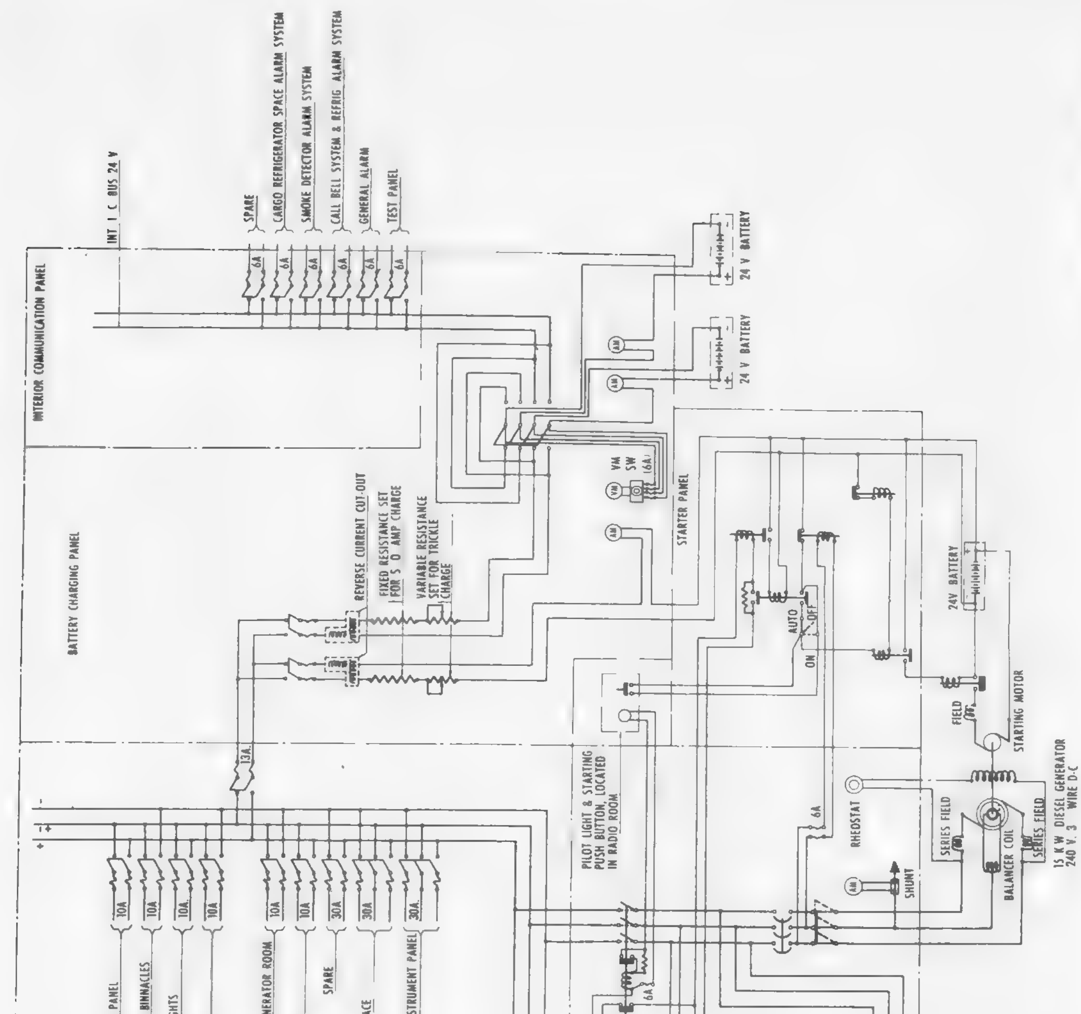


Figure 64b.—Schematic diagram of emergency switchboard.



Courtesy of Cornell Maritime Press.

Figure 65.—Elementary diagram of emergency generator and switchboard connections.

1. A selector switch to select either of the ship's service feeders as the normal feeder.

2. A ship's service bus-transfer-control power switch which sets up the bus-transfer control for either automatic or manual operation.

3. An emergency bus-transfer-control power switch which sets up the bus-transfer control for either automatic or manual operation.

4. A test switch which, when operated, sets up circuit conditions to simulate a power failure on the ship's service feeders and thereby automatically starts the Diesel engine. The emergency bus-transfer unit does not, however, operate under these conditions, permitting a test to be conducted without disturbing the otherwise normal operation of the switchboard.

5. A control test switch for manual operation of the ship's service bus transfer when 2 is in the correct position for manual operation.

6. A control test switch for manual operation of the emergency bus transfer when 3 is set for manual operation.

A detailed analysis of the bus-transfer-control circuits is not considered necessary for the purposes of this book. Manufacturers' instruction books are referred to for a detailed description of the individual devices and their operation.

The remaining equipment on the emergency switchboard of a combat ship includes the meters, control switches, circuit breakers, and voltage regulator ordinarily provided on a switchboard for the control and protection of an a-c generator and of distribution circuits.

Emergency Switchboards on Auxiliary Ships

Emergency switchboards on auxiliary ships ordinarily operate in d-c systems and are of the type usually furnished on merchant vessels. Provision for automatic starting of the Diesel engine and automatic bus transfer is generally made.

On a typical AKA ship, a 15-kilowatt Diesel emergency switchboard has connections and switching as shown in the elementary diagram of figure 65.

Miscellaneous Switchboards

STEERING-POWER TRANSFER SWITCHBOARD

Steering-power transfer switchboards are provided on combat ships for selection and automatic transfer to steering-gear power sources. The one-line diagram of figure 66 shows the principal switching and circuits of a transfer switchboard installed

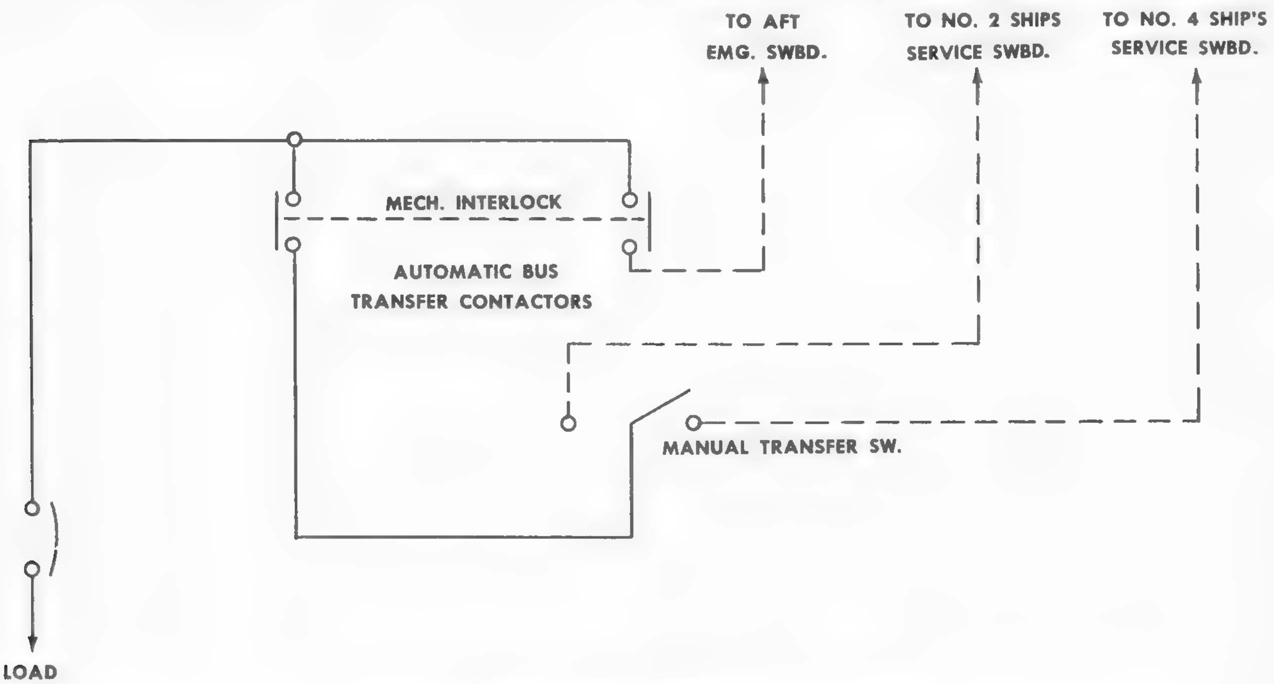


Figure 66.—Steering-transfer switchboard (one-line diagram).

on an *Essex* class carrier. This is typical of the arrangement used on large combat ships.

The 450-volt, three-phase, 60-cycle, a-c normal ship's service steering supply is obtained from the No. 2 or No. 4 ship's service switchboard, depending on the position of the manual transfer switch.

Automatic bus-transfer contactors shift the steering-gear load from the normal ship's service supply to the emergency supply when there is a power failure on the normal supply.

A control and test switch serves for transfer of control for the bus-transfer contactors from auto-

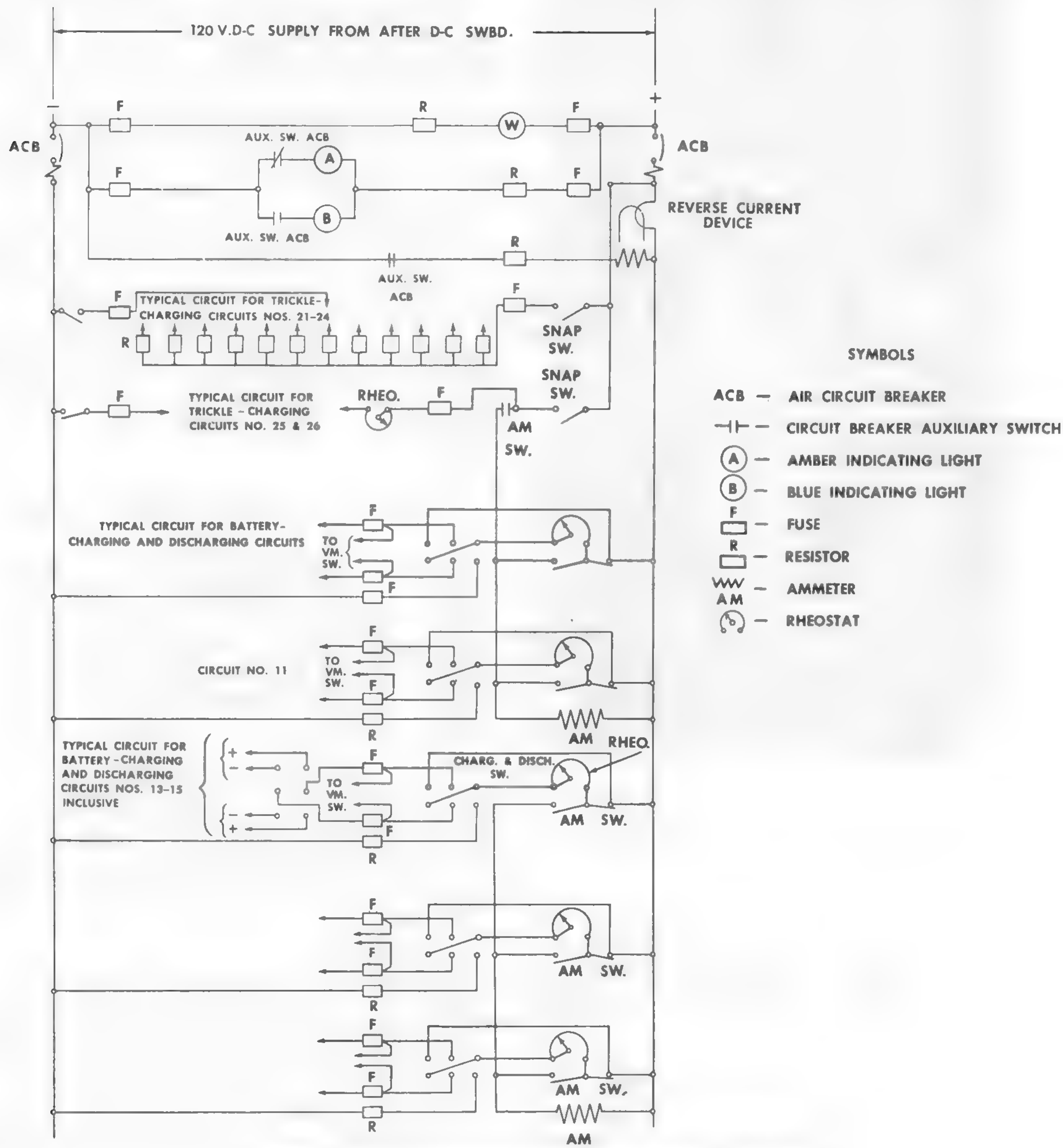
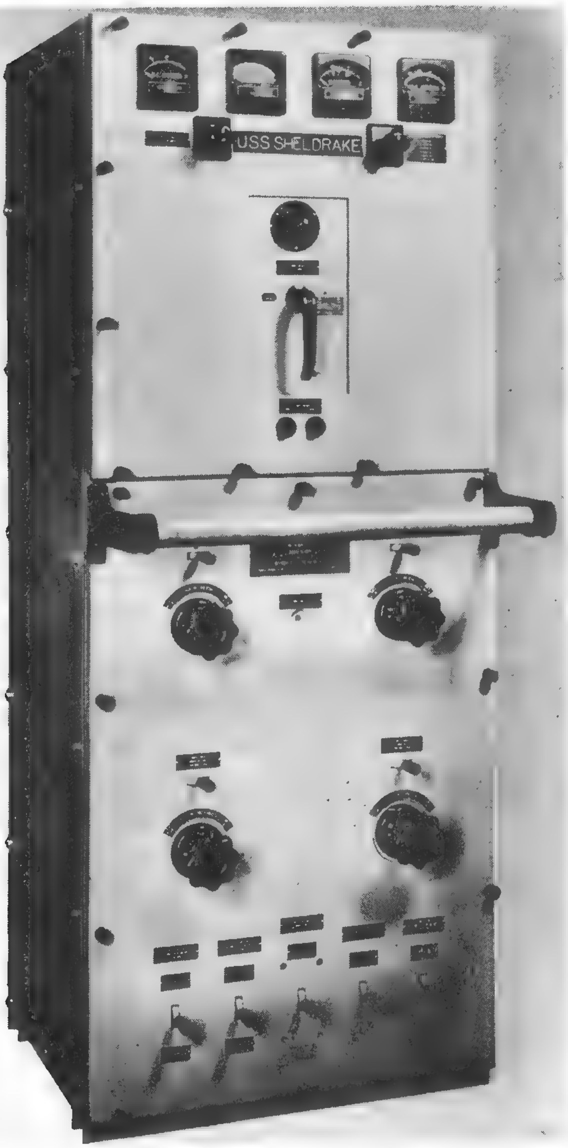


Figure 67.—Elementary wiring diagram of battery-charging switchboard.



Courtesy of Westinghouse Electrical Corp.

Figure 68.—Battery-charging switchboard.

matic to manual or vice versa. This switch is also used to test the bus-transfer equipment by simulating a power failure in the normal power supply and thereby causing transfer to the emergency source.

AUXILIARY D–C SWITCHBOARDS

A source of d-c power supply is required on a-c ships for interior communication, battery charging station, and searchlights. This power is usually supplied from one or more a-c/d-c motor generator sets in a two-wire, 120-volt system.

On large combat ships a forward- and an after-motor generator set with their associated switchgear are installed. The generator of each set is usually driven by a three-phase, 450-volt induction motor and is of sufficient capacity to supply the d-c ship's service load. Both generators are shunt machines and are suitable for parallel operation with each other.

The d-c switchboards include meters, circuit breakers, and control devices ordinarily installed for control of d-c generators and distribution circuits.

The generators may be paralleled through the bus-tie between switchboards. Parallel operation is only necessary when the load of one machine is to be shifted to the other. The bus-tie also serves the purpose of supplying the loads of both switchboards from a single generator when it is desirable or necessary to take a machine out of service. Under battle conditions the generators are operated independently.

BATTERY-CHARGING SWITCHBOARD

The battery-charging switchboard of a large aircraft carrier is a good illustration of the type of control required for charging a variety of portable storage batteries aboard ship. The main features incorporated into the switchboard are best analyzed by examining the elementary wiring diagram of figure 67.

The various charging circuits of the switchboard are fed from the 120-volt d-c supply of the after d-c switchboard through a manually operated circuit breaker. The circuit breaker is equipped with reverse current trip to prevent feed back from the batteries. Indicating lights are provided to show the circuit breaker position and to indicate when power is available.

Trickle charging circuits are provided for charging batteries at a slow rate. The typical circuit shown in figure 67 can charge several batteries at the same time through the charging resistor branches.

Double pole, double-throw transfer switches are used for charging and discharging batteries through a fixed resistance and a variable rheostat. Setting

the variable rheostat controls the charging or the discharging current. Batteries are only discharged for occasional check of their capacity.

The charging current or discharge current of any battery-charging circuit can be read from an ammeter when the circuit ammeter switch is closed. There are two ammeters for this purpose. One is connected to battery circuits having a maximum charging rate of 40 amperes and the other to circuits having a maximum charging rate of 20 amperes. A third ammeter is connected directly in the source circuit for reading the total current supplied to the board.

A voltmeter with two selector switches is installed with connections to the various charging circuits. The two selector switches are interconnected to provide the number of positions required.

The front view of a typical battery-charging switchboard for a combat ship is shown in figure 68.

Instruments

D–C Ammeters and Voltmeters

Ammeters and voltmeters for use on direct current are usually of the permanent magnet moving-coil type. These instruments operate on the principle that a coil may be so placed in a magnetic field, that it will tend to rotate when current is passing through it.

The moving coil of an ammeter or voltmeter is supported by hardened pivots in jewel bearings and when energized by a current turns against the force of a spring. The coil will turn until its deflecting torque is balanced by the restoring torque of the spring. The deflecting torque is proportional to the magnetic field of the coil and this in turn is proportional to the current flowing in the coil. The amount of deflection of the moving coil is therefore a measure of current in the coil and with a properly calibrated scale and pointer, the current or voltage of a supply can be read.

The cross section of wire in ammeter coils is as large as practicable in order to keep the voltage drop across the instrument as low as possible. The actual current in the coil of an ammeter is usually only a small part of the current being measured, the greater part being by-passed through a shunt.

The construction of a voltmeter does not differ materially from an ammeter. The moving coil, however, is usually wound with more turns and with finer wire than the ammeter and so has a higher resistance. Since a voltmeter is connected across the line, the resistance of its coil circuit must be high in order to keep the current within practical limits. The resistance of the coil is therfore supplemented with a high resistance connected in series with it, this resistance being an integral part of the voltmeter.

A–C Ammeters and Voltmeters

Switchboard ammeters for use on alternating current are usually of the moving-iron type.

In the moving-iron type, one or several pieces of soft iron or magnetic alloy are caused to move by the magnetic field of a fixed coil or coil system carrying the current to be measured. The value of the current is indicated by the position of a pointer when the torque caused by the current is balanced by spiral springs.

Figure 69 shows the principal features of a typical type of switchboard a-c ammeter or voltmeter. This instrument combines attraction and repulsion principles of operation.

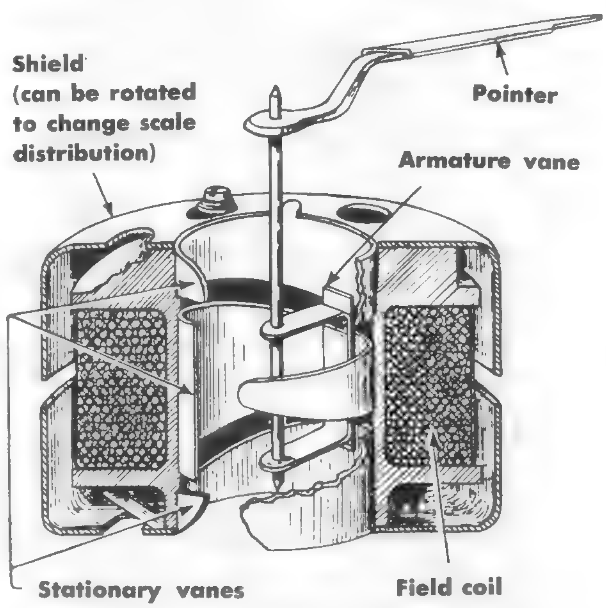


Figure 69.—A-c ammeter or voltmeter (sectional view).

Three stationary vanes of carefully determined configuration are mounted inside of a field coil which, when energized, magnetizes the fixed vanes and a vane attached to the moving shaft.

The central vane exerts a force of repulsion in the direction of the taper, or up-scale. The upper and lower vanes attract the moving iron in the direction of increasing vane width, or up-scale.

A-c ammeters are usually self-contained for measuring currents up to 20 amperes. Where currents exceed this value, ammeters are connected to the secondaries of current transformers, the primaries of which are connected in series with the circuit.

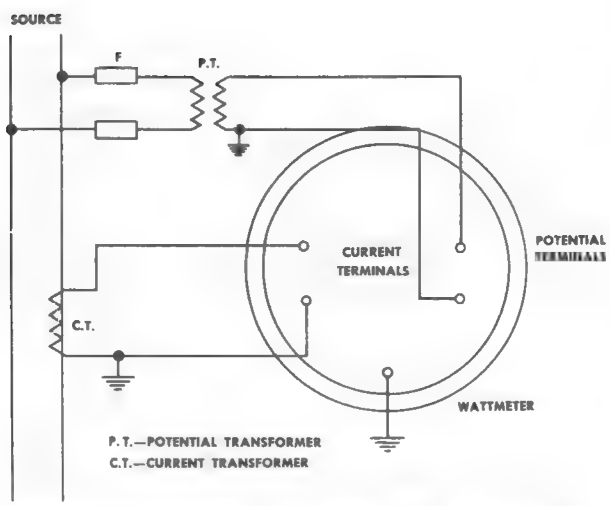


Figure 70.—Connections for single-phase wattmeter.

A-c voltmeters are connected to 450-volt circuits through potential transformers. The voltmeter is connected to the secondary of the transformer and the transformer primary is connected across the circuit. When the circuit voltage is 115 volts the voltmeter is connected directly across the line.

Wattmeters

The wattmeter is used almost exclusively for the measurement of power in a-c circuits since the power is more accurately given in direct current circuits by the product of the voltage and current.

Wattmeters are usually of the electrodynamometer type. In a single-phase wattmeter, a moving coil is mounted on pivots and jewel bearings and turns in the magnetic field of a fixed coil. The moving coil is connected across the line to carry a current proportional to line voltage and the stationary coil is connected in the line, to carry a current proportional to line current. The torque exerted on the moving coil acts against the torque of spiral springs and the pointer fastened to the moving coil assumes positions on a graduated scale when the two torques are balanced. The scale is calibrated to read the power directly in watts.

The potential element of the wattmeter contains a resistance in series with the coil to reduce the coil current. The current element is wound with wire of relatively large cross section so that the voltage drop across the instrument is small.

Single-phase switchboard wattmeters on 450-volt circuits have the potential element connected to a potential transformer and the current element connected to a current transformer as shown in figure 70.

The sectional view of figure 71 shows the arrangement of the principal elements of a wattmeter.

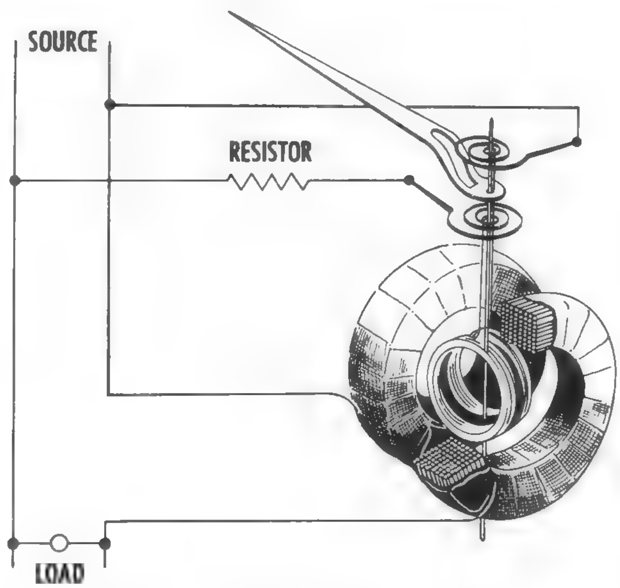


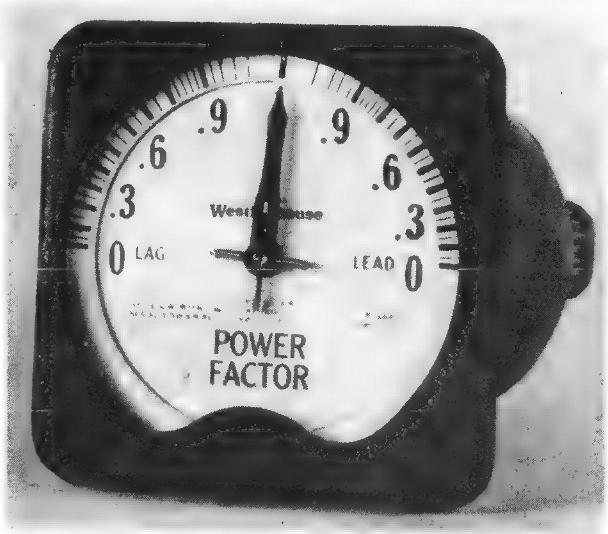
Figure 71.— Schematic diagram of a wattmeter.

Power Factor Meters

The scale of a power factor meter reads power factor direct in terms of the cosine of the angle of lead or lag as illustrated in figure 72.

Power factor meters on naval ships depend for their operation on the interaction of a field produced by a current element connected in the line and a rotating field produced by two or more potential coils. The moving elements may be the current coil, the potential coils, or an iron vane magnetized by the current coil. The moving element assumes a position where the maximum value of the current-coil field is lined up with the rotating field.

A typical power-factor meter consists of a standard three-phrase stator with distributed windings operating in conjunction with a moving-iron element which has an independent exciting coil. The rotor exciting coil is the current coil of the instrument and the stator coils are connected across the line. Connections are as shown in figure 73.



Courtesy of Westinghouse Electrical Corp.

Figure 72.—Dial of power factor meter.

Frequency Meter

There are several different types of frequency meters in use which employ various combinations of fixed and moving coils. The type which is commonly supplied with switchboards consists principally of a double-section stationary coil, a rotating coil with pointer, an impeder and a restoring coil. The arrangement of those parts is shown in the sectional view of figure 74.

The external impeder, consisting of two capacitor-reactor networks, supplies two currents, one increasing and one decreasing with frequency change. These circuits energize the double-section field coil so that the indication of the moving system is a function of the ratio of the two currents which is in turn dependent only on the frequency. Connections for this type of frequency-meter and its external impeder are shown in figure 75.

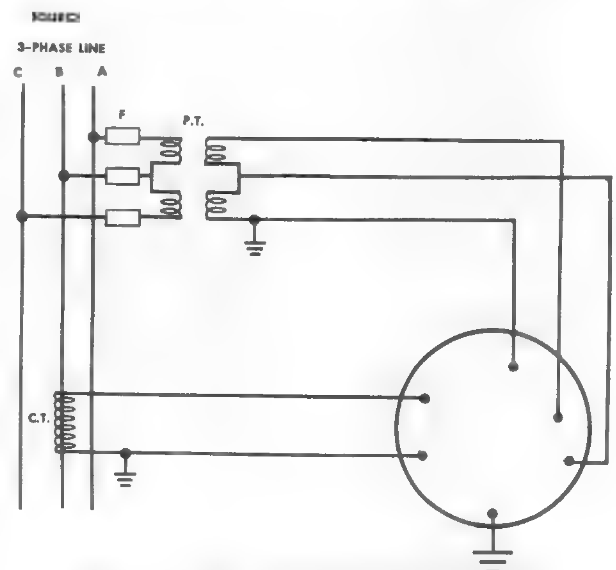


Figure 73.—Typical power factor meter connections.

Synchroscope

The *synchroscope* is a switchboard instrument designed to indicate the phase difference between the two sources of electromotive force to which the instrument is connected. It is used exclusively for the purpose of synchronizing an a-c generator with an energized bus prior to making the necessary connections for parallel operation, and for synchronizing the local bus with the bus-tie.

The synchroscope shows whether the frequency of the incoming machine is greater or less than the bus frequency, the amount of difference in frequencies, and gives an accurate indication of the moment that the machine is in phase with the bus.

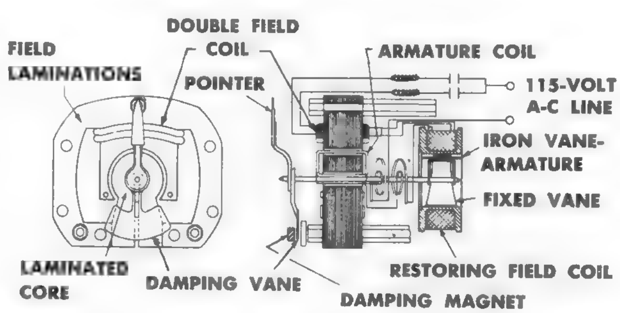


Figure 74.—Sectional view of frequency meter.

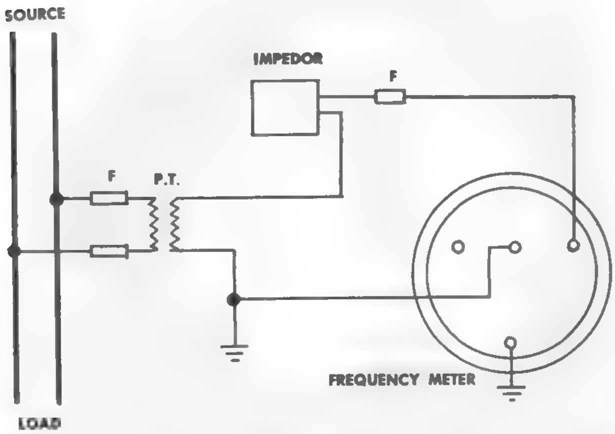


Figure 75.—Typical connection diagram for frequency meter.

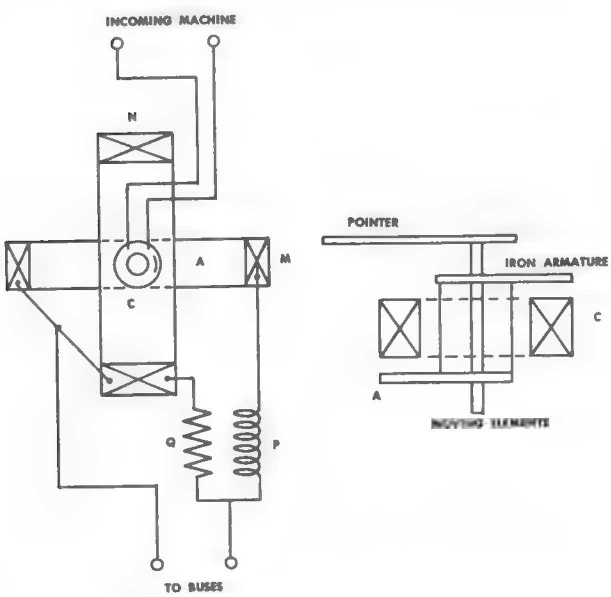


Figure 76.—Schematic diagram for typical synchroscope.

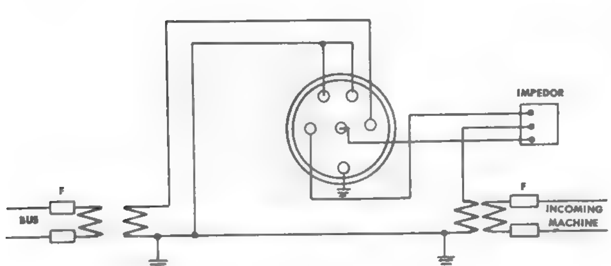


Figure 77.—Connections for a typical synchroscope.

The principle of the type of synchroscope generally used aboard ship is shown in figure 76 where a rotating field is produced by coils *M* and *N* connected to the buses through the reactance *P* and the resistance *Q* respectively.

An iron vane *A*, free to rotate, is mounted in this rotating field and magnetized by the coil *C*, which in turn is connected across the incoming machine. As the vane is attracted or repelled by the rotating field, it will take up a position where this field is zero at the same time the field from *C* is zero. The position at any instant is therefore an indication of phase difference. When the two frequencies are different this position changes and the pointer rotates in either a clockwise or counterclockwise direction depending on whether the incoming machine is fast or slow with respect to bus frequency.

When a synchroscope is properly connected, synchronism is indicated when the pointer is straight up. When the pointer is revolving counterclockwise the incoming machine is slow and when the pointer is revolving clockwise the incoming machine is fast. The circuit breaker of the incoming machine is closed when the pointer slowly passes the synchronizing point. Connections for a typical switchboard synchroscope are shown in figure 77.

Current Transformers

Alternating-current instruments with current coils are usually operated through current transformers. In this way the instruments are isolated from the line potential and operate at the comparatively low values of secondary currents which maintain a fixed ratio with actual load currents. Current transformers therefore make possible the measurement of heavy currents with relatively small instruments of standardized design.

Current transformers are classed in three types—wound, bar, and window. These classifications are descriptive of the primary construction; the wound type having one or more primary turns; the bar types having a straight copper bus bar forming a single turn primary winding; and the window type for measuring high currents where a primary is not required and the bus bars pass through a window-like opening in the secondary.

Current transformer secondaries should never be open circuited when the primary circuit is energized. An open secondary results in an excessive secondary voltage which is dangerous to personnel and is likely

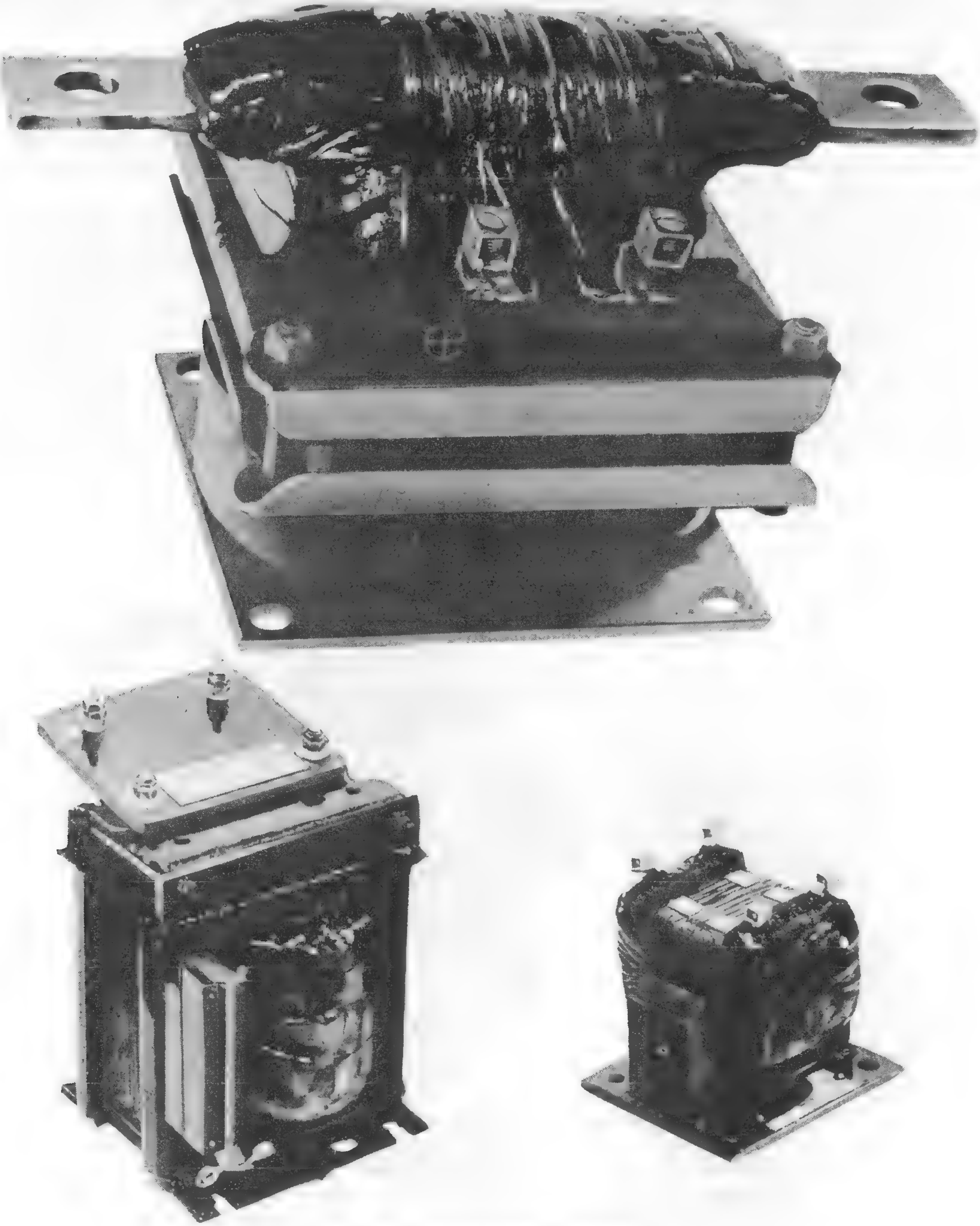


Figure 78.—Typical instrument transformers.

to damage the transformer. Precautionary measures are taken on many installations aboard ship by the addition of a voltage protection device which automatically short circuits the secondary if it is accidentally opened.

Potential Transformers

Potential transformers are used on all 450-volt circuits to isolate the instruments from the line potential and to make possible the use of lower voltage instruments of more standardized design. Potential transformers for Navy use are designed for a rated secondary voltage of 110 volts and for primary voltages ranging from 230 to 6,600 volts.

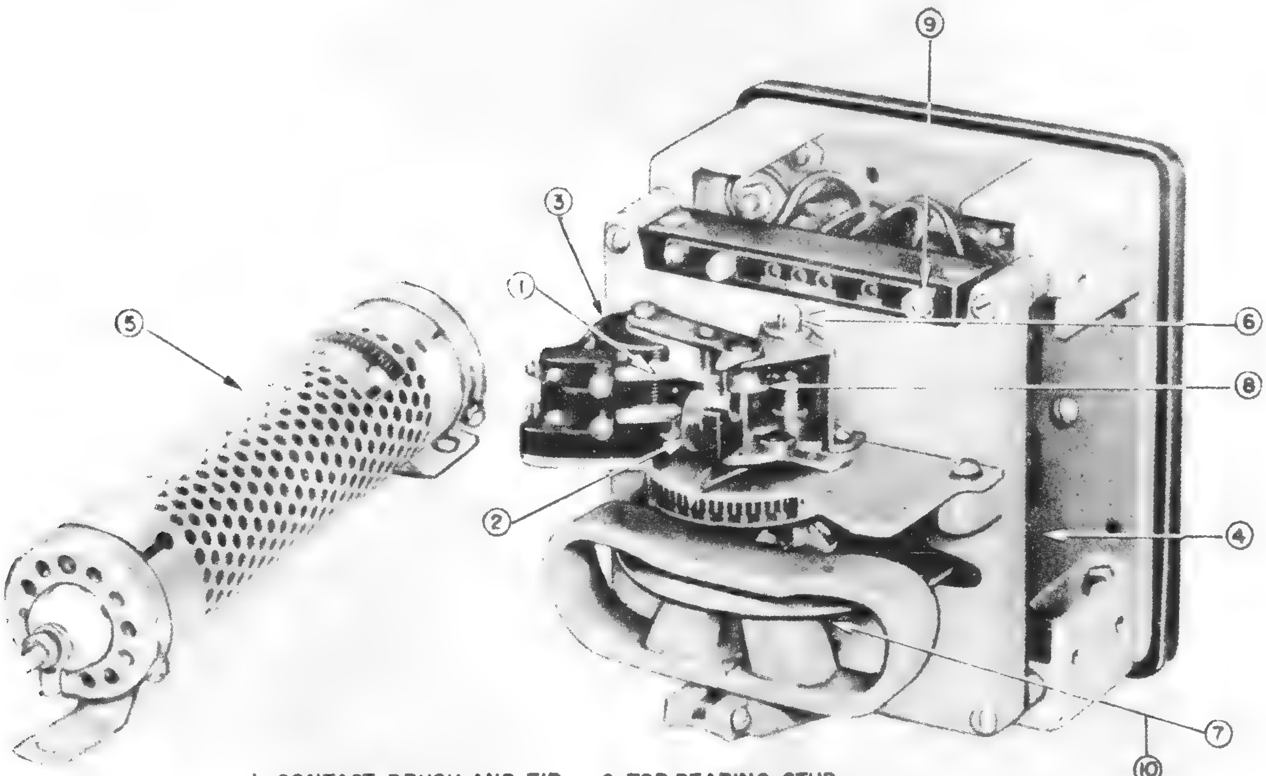
Potential transformers should have one side of the secondary and the metal case grounded to prevent the secondary from assuming line potential in the event of a breakdown in insulation between primary and secondary.

Typical instrument transformers are shown in the photos of figure 78.

Reverse Power Relay

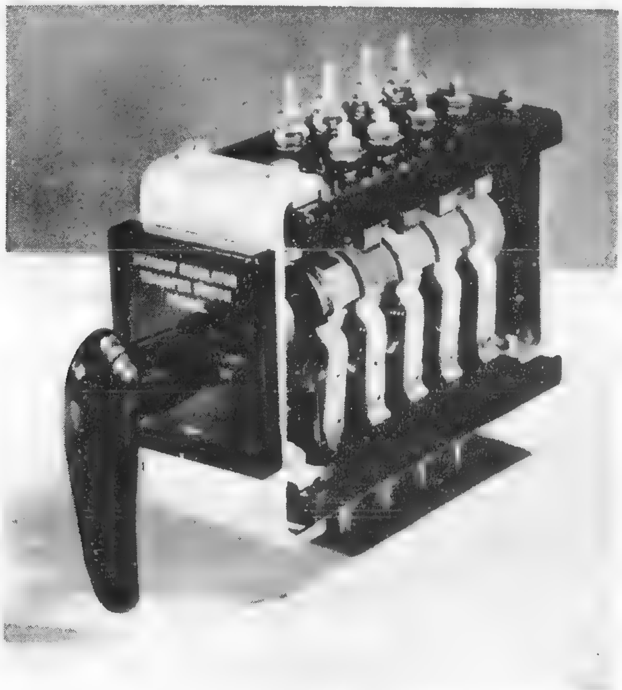
Reverse power relays are installed with all a-c generators designed for parallel operation to prevent the motoring of a generator in the event of a prime-mover failure.

The type of relay used is of the induction-disk construction. It consists of a laminated iron structure with a pole projecting downward from the top and two poles projecting up from the bottom. A disk is located between the top and bottom poles and rotates on its shaft owing to the interaction of the fields produced by the poles. The coil on the upper pole is connected in series with a resistor and forms the potential circuit. The two coils on the lower poles are connected in series to form the



1. CONTACT BRUSH AND TIP
2. CONTACT DISK
3. HOLDING COIL
4. PUNCHINGS AND COILS
5. EXTERNAL RESISTOR
6. TOP BEARING STUD
7. JEWEL SCREW (NOT VISIBLE ABOVE).
8. CONTROL SPRING
9. TAP PLUG
10. PIVOT

Figure 79.—Reverse power relay.



Courtesy of Westinghouse Electrical Corp.

Figure 80.—Rotary control and instrument switch.

current circuit. The disk shaft is geared to a second shaft which carries the contacts and a spring for resetting the contacts. The assembled relay is shown in figure 79.

These relays are responsive to the product of current and voltage applied to their windings and a function of the phase angle between them. With a typical relay of this type the design is such that the maximum torque is produced when the current leads the voltage by 30 degrees.

Permanent magnets situated at the front of the relay set up a drag force on the disk to give a time delay in closing the contacts after current and voltage are applied.

Control and Instrument Switches

The control and instrument switches installed on switchboard control panels are of the rotary cam-operated type and are used to close or open circuit breakers electrically, to control prime mover governors, and to transfer regulators and meters from one circuit to another. The general appearance of this type of switch is shown in figure 80.

In this figure notice that the switch is made up in a number of stages to suit the switching application involved. Rotation of the switch shaft causes contacts to close or open according to the shape and setting of the cams in the various stages. Each stage has one or two contacts with two or three cams. The operation of cams with the moving contacts is shown in figure 81.

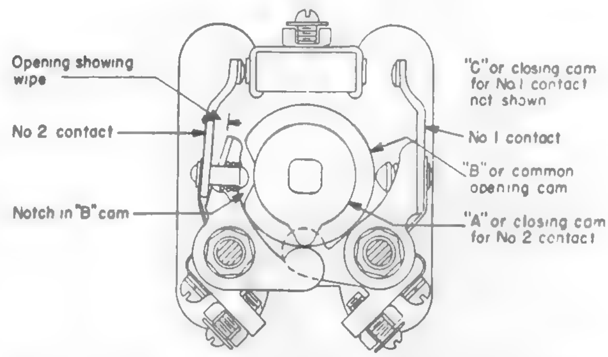


Figure 81.—Typical section showing operation of cams (front view).

Circuit Breakers

The importance of the electrical system to the fighting effectiveness of a naval ship necessitates the most careful consideration to the design and application of circuit protective devices. Naval service requires that circuit breakers operate satisfactorily under conditions of high impact shock. This requirement is probably the most outstanding single feature of circuit breakers developed for the Navy; it differentiates them from equipment ordinarily applied on commercial vessels.

Soon after the problem of high impact shock was recognized, there was developed the so-called grade-B-circuit breakers designed to withstand the effects of high impact shock mechanically but provided with lock-in devices to prevent electrical misoperation when the intensity of shock exceeded 150 pounds. The development of improved overcurrent tripping devices with anti-shock features has made possible the manufacture of grade A breakers which are shockproof for high-impact shock both electrically and mechanically.

From the electrical standpoint the design of circuit breakers has been governed by the requirements of the ship's power distribution system with respect to fault protection. The basic requirements are listed on the following page.

1. High speed clearing of faults.
2. Selective operation under fault conditions.
3. Maximum protection of electrical apparatus and circuits.
4. Adequate interrupting capacity in all circuit interrupting devices.
5. Adequate thermal capacity in all circuit protective devices.
6. Simplicity of operation and ease of maintenance.

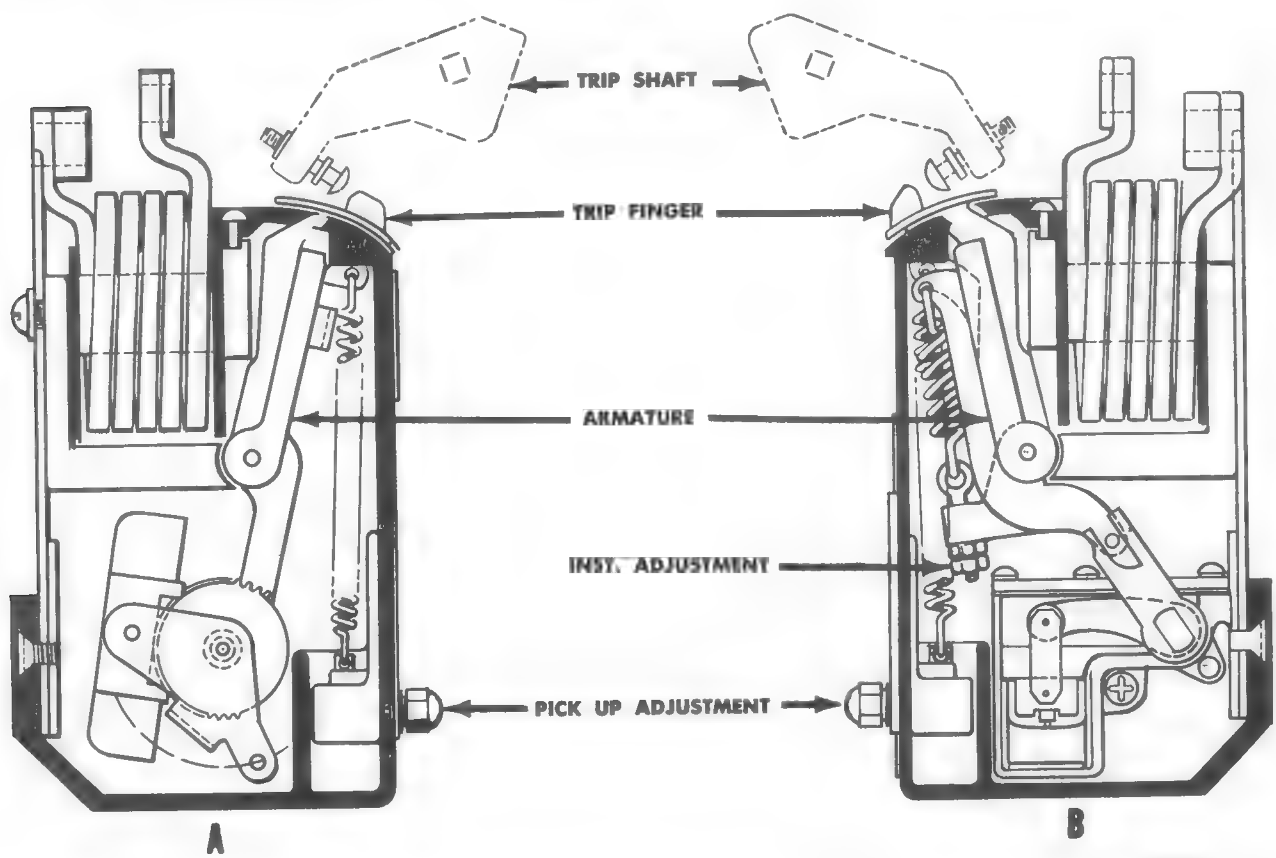
The two major types of circuit breakers employed on naval combatant ships are known as the type ACB and the type AQB.

Type ACB are circuit breakers with an open metallic frame and are adaptable to all of the various protective functions. They are used to connect ship's service and emergency generators to the power distribution system, on bus-ties and shore connection circuits and on all feeder circuits emanating from the main bus of switchboards where the maximum available short-circuit current exceeds the interrupted rating of a type-AQB circuit breaker. Generator and bus-tie type-ACB breakers on the larger installations are electrically operated.

Type AQB circuit breakers have supporting and enclosing housings of insulating material with direct-acting automatic tripping devices. These breakers are designed in the lower-interrupting capacity ratings and are generally confined in their application to distribution circuits where the maximum demand load does not exceed 600 amperes and maximum short-circuit current are relatively small.

TYPE ACB CIRCUIT BREAKERS

Three important protective devices are built into the type-ACB circuit breaker to achieve the objectives of fault protection in distribution systems. These devices are classified in their separate functions of establishing three distinct time current tripping characteristics which are outlined as follows:



Courtesy of Cornell Maritime Press.

Figure 82.—Two-armature, three-element overcurrent tripping device.

1. A relatively long time delay in a range of currents up to 300 to 400 percent of the circuit rating.

2. A very short time delay for currents in a range above these values.

3. Instantaneous tripping at currents above a certain value. The latest series overcurrent tripping device shown in figure 82 is a three-element device which combines the necessary characteristics into a single unit.

This device has two armatures associated with a common magnetic circuit and series coil. One armature operates the long-time and instantaneous element and the other operates the short-time element.

The long-time element (figure 82-B) is of the positive-displacement type utilizing a piston equipped with a fixed orifice in a cylinder of oil. The piston orifice is of a size suitable for the time characteristic desired. Silicone oil is used to minimize the effects of temperature change and to avoid sludging. Under current conditions permitting long time delay, the armature works against the restraining force of the piston's movement in the oil. If the condition persists through the time delay period, the tripping shaft of the circuit breaker is engaged and the breaker is opened by heavy spring pressure.

The armature of the long-time element is linked to the piston through a heavy spring which provides the instantaneous feature of the device. The restraining force of this spring is only overcome by currents where instantaneous tripping is desired and when that condition takes place the armature closes independent of the long-time oil displacement element.

The short-time armature operates an escapement-type mechanism, (figure 82-A), which produces an inverse time characteristic. The escapement wheel is made with teeth only on part of its periphery. Thus the delay is set by varying the position in the stroke of the armature at which the escapement wheel runs free of the pallets.

Each circuit breaker in a three-phase alternating-current circuit is equipped with two complete overcurrent units with one in each outside leg of the circuit. On d-c systems with the generator neutral brought out, three overcurrent units are provided with each circuit breaker for the positive, negative, and neutral leads.

Type-ACB circuit breakers are designed for high-speed tripping, effective quenching of arcs, and simplicity in operation. The main current-carrying contacts are closed against the restraining forces of heavy springs which quickly restore the moving contacts to their open position when the closing latch is released by the tripping mechanisms.

The assembly drawing of figure 83 shows the component parts of a breaker exclusive of the tripping mechanisms previously described.

When the contacts are closed by the operating mechanism, the arcing contacts close first and are followed by the closing of the main bridging contacts. When the breaker opens, the main contacts open first; this action shunts the current through a flexible connection to the arcing contacts; thus it prevents burning of the main silver contacts. The arcing contacts then open and when they pass under the front of the arc runner, the current is in turn shunted to the arc runners over a flexible connection. The arc is then directed up through the arc quencher where the circuit is quickly opened.

Arc quenchers are of various designs depending on the manufacturer. A typical type utilizes the de-ion principle which amounts to lengthening and cooling the arc through a series of baffles and copper pins. Steel magnets of the arcing contacts form a magnetic circuit which blows the arc off the arcing contacts when the arcing contact passes under the arc runner.

As the arc travels up the arc runners and through the pins, it is lengthened and cooled so that the circuit is quickly opened. The arc is confined to a fixed path of travel by a box type barrier of molded compound provided to fit over the top, sides, and front of the arc quenchers.

Other components of the ACB-type breaker include the following:

1. Mechanical indicator to show whether the contacts of the breaker are open or closed.

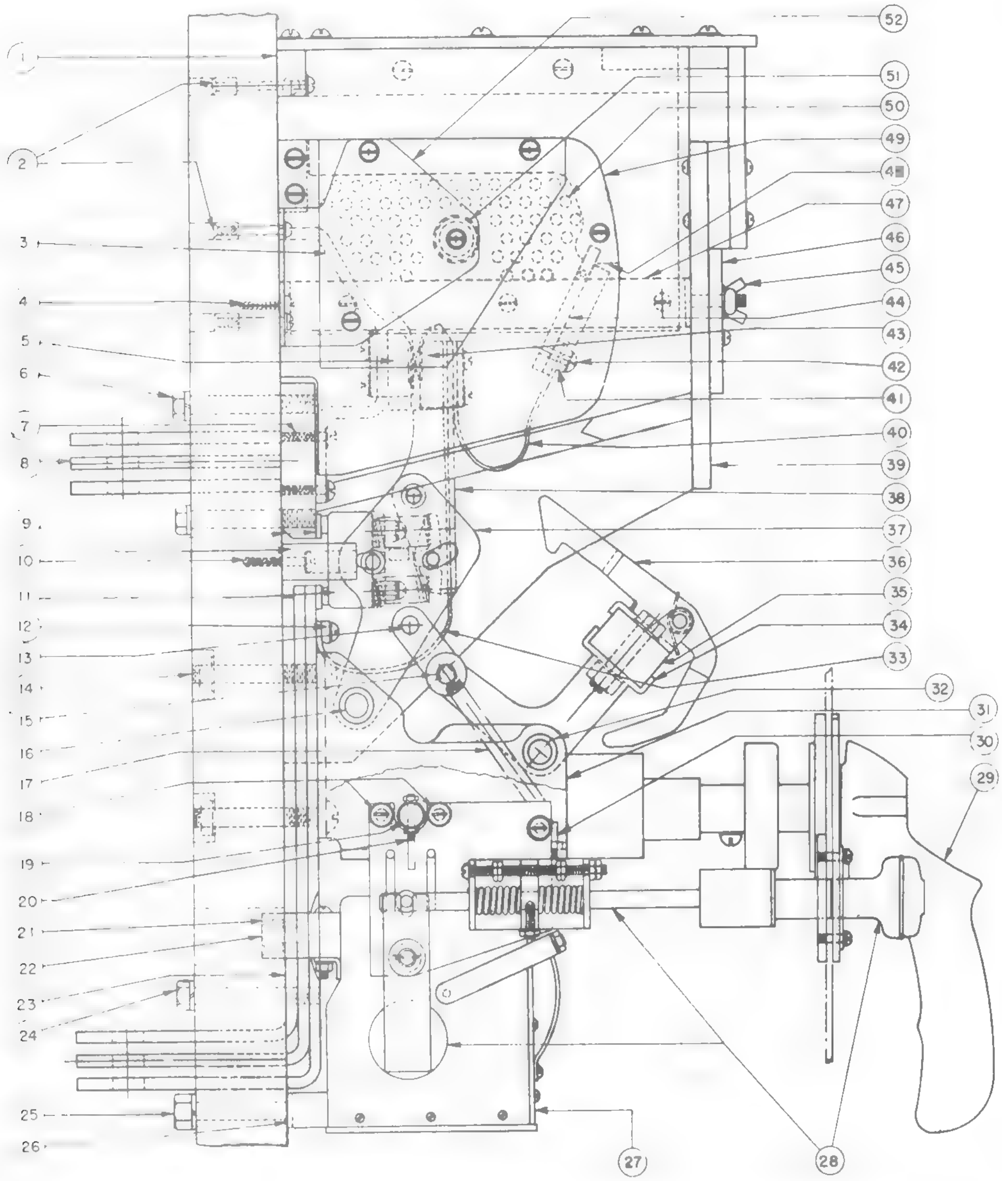
2. Auxiliary switches as required. The minimum switches consist of one set normally open when the circuit breaker is open and one set normally open when the breaker is closed.

3. A handle for closing the circuit breaker manually.

4. Equipment for electric closing as required.

5. Reverse current protection for d-c installations integral with the circuit breaker.

6. Instantaneous no-voltage tripping device for direct current applications. The drop-out voltage with this device does not exceed 50 percent of the normal voltage.



1 BARRIER BRACKET
2. SCREW RH. 10-24 WITH EXP. SCREW ANCHOR, WASHER, AND LOCKWASHER
3. REAR ARCING HORN
4. SCREW, SELF TAPPING RH. #14 X $1\frac{1}{4}$" WITH LOCKWASHER
5. STATIONARY ARCING CONTACT ASSEMBLY
6. SCREW HEX. HD. $\frac{3}{8}$-16 AND LOCKWASHER
7. SCREW RH. #10-32 X 1" AND LOCKWASHER
8. UPPER STUD AND STUD BLOCK WITH SILVER CONTACT
9. BAFFLE
10. SCREW, SELF-TAPPING RH. #10 X 1" WITH LOCKWASHER
11. BRIDGING BLOCK ASSEMBLY WITH SILVER CONTACT
12. CLAMPING PLATE
13. PIN IN CONTACT SUPPORT WITH WASHER AND COTTERS
14. SCREW RH. $\frac{3}{8}$-16 WITH WASHERS AND NUT
15. PIN IN TOGGLE LINK
16. PIN IN FRAME
17. OPENING SPRING FOR POLE WITHOUT MECHANISM
18. SCREWS, RH. $\frac{1}{4}$-20 X $\frac{3}{8}$" WITH LOCKWASHERS
19. INTERLOCK TRIP ROD, RIGHT AND LEFT
[illegible] PIN, NUT, AND LOCKWASHER
21. SCREW F.H. #10-32 X $\frac{7}{8}$
22 MAGNET
23. LOWER STUD WITH SILVER CONTACT
24. SCREW HEX HD. $\frac{3}{8}$-16 WITH LOCKWASHER
25 SCREW HEX. HD. $\frac{3}{8}$-16 WITH LOCKWASHER
26 FIBRE SHIM
27 TIME DELAY SHORT CIRCUIT TRIP DEVICE
28 MANUAL TRIP AND HOLD-IN DEVICE AND COUNTERWEIGHT
29 OPERATING HANDLE
30. SPRING POST
31 FRAME
32 PIN IN FRAME
33 FLEXIBLE CONNECTIONS
34 TOGGLE LINK
35 CROSS BAR ASSEMBLY
36. CATCH ASSEMBLY
37. MAIN CONTACT SUPPORT
38. MOVABLE ARCING CONTACT SUPPORT
39. [illegible]
40. FLEXIBLE CONNECTION
41. CLAMPING PLATE
42. SCREW RH. 10-32 X $\frac{3}{4}$" WITH LOCKWASHER
43. MOVABLE ARCING CONTACT ASSEMBLY
44. FRONT ARC RUNNER
45 WING NUT $\frac{1}{4}$-20 WITH WASHER
46. REMOVABLE INSPECTION PLATES
47. SUPPORT STRAPS WITH WELDED SCREWS $\frac{1}{4}$-20
48. ARC BAFFLES
49. ARC QUENCHER SIDE PLATES
50 COPPER PINS
51 MAGNETIC PIN
52 ARC QUENCHER BRACKET

Figure 83.—Assembly drawing of type-ACB circuit breaker.

7. Shunt tripping device as required for remote tripping.
8. Hold-in button to prevent overcurrent tripping.

Type-ACB circuit breakers are furnished in the following standard frame sizes, interrupting ratings, and circuit-breaker ampere ratings with overcurrent trip coils as listed.

TABLE 2.—*Type ACB circuit breakers.*

Frame size	Interrupting rating: R. M. S. 500 volts 60 cycles, a-c	Interrupting rating: 250 volts d-c (max.)	Circuit-breaker copper rating	Overcurrent trip coil
Amperes	*Amperes*	*Amperes*	*Amperes*	*Amperes*
225	20,000	15,000	250	25 40 50 80 100 160 250
600	40,000	25,000	640	40 50 80 100 160 250 320 400 480 560 640
1,600	60,000	50,000	800	100 160 250 320 400 600 800
			1,600	1,000 1,200 1,400 1,600
3,000	75,000	60,000	2,000	2,000
			3,000	2,400 3,000
4,000	100,000	60,000	4,000	4,000

AQB AND NQB CIRCUIT BREAKERS

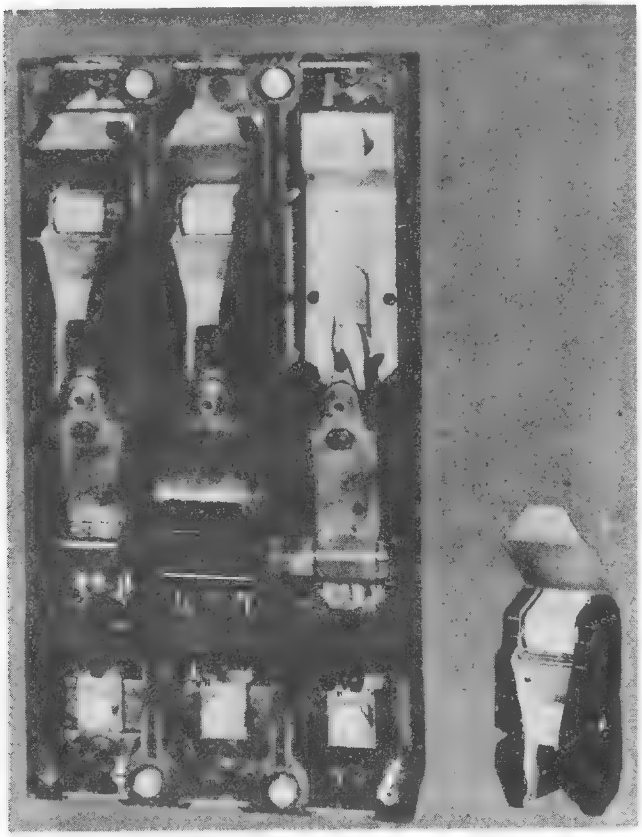
AQB-type circuit breakers are furnished in 100-, 225-, and 600-ampere frame sizes. They are enclosed in molded insulation housings with the operating handle and hold-in button also of insulating material being the only movable parts visible. The general appearance of the type AQB breaker is shown in figure 84.

Courtesy of Westinghouse Electrical Corp.

Figure 84.—Exterior view of type-AQB circuit breaker.

Inverse time-delay tripping is provided by thermal elements which are calibrated to operate in a 50° C ambient temperature. The breaker trip element is calibrated so that it will not trip in less than one hour on 150 percent of rated current and to trip within one hour on 225 percent of rated current.

Series magnetic coils and their corresponding magnetic circuits and armatures are utilized to provide the instantaneous tripping characteristic



Courtesy of Westinghouse Electrical Corp.

Figure 85.—Interior of view type-AQB circuit breaker.

required. The magnetic trip calibration is set at 600 to 700 percent of current rating on a-c and d-c breakers of the 225- and 600-ampere frame sizes with the exception of certain elements designed particularly for a-c motor services. These have a magnetic calibration of 1,200 to 1,400 percent.

Both thermal and magnetic tripping elements are combined in a removable "trip unit." Trip units of the various current ratings within a particular frame size are interchangeable for a given manufacturer so that the rating of a particular circuit breaker may be changed before and after installation by interchanging trip units. Trip units are provided in each pole of type-AQB circuit breakers.

The closing and opening movements of the interior operating mechanism are by a "quick-make" and "quick-break" action independent of the rate at which the handle is moved. Automatic trip devices trip free of the handle so that the breaker cannot be held closed with the handle if a tripping condition exists.

Stationary and moving contacts are of a silver-tungsten alloy which will not weld even on extremely high currents and can endure, without appreciable loss of mass, the momentary arc when rupturing current.

The de-ion type of breaker has arc extinguishers consisting of steel plates spaced apart by sides of refractory insulation. The plates have a V-slot within which the arc is formed and, by the magnetic attraction set-up, is forced into the apex of the "V." Here the arc is trapped, its energy absorbed, and the space deionized so that the current is interrupted in a short time. At the bottom of the extinguisher is a steel arc runner to which the arc transfers from the contacts, thereby saving the stationary contacts from severe deterioration. Arc horns on the moving contacts similarly protect the moving contacts.

The interior appearance of the type AQB circuit breaker is shown in figure 85.

Type AQB circuit breakers are furnished in the following frame sizes and interrupting ratings with any one of the standard trip unit ratings:

TABLE 3.—*Type AQB circuit breakers*

Frame size	Interrupting rating		Trip unit rating
	R. M. S. 500 volts 60 cycles, a-c	250 volts d-c (max.)	
Amperes	*Amperes*	*Amperes*	*Amperes*
100	15,000	10,000	15, 25, 50, 75, 100
225	20,000	15,000	125, 150, 175, 225
600	30,000	20,000	250, 300, 350, 400, 500, 600

Type NQB circuit breakers are similar to type AQB breakers except that they are not provided with any automatic overcurrent protection. They are supplied in the 100-, 225-, and 600-ampere ratings only.

Operation and Maintenance

The operation of switchboards is concerned entirely with those functions discussed in the previous chapters which relate to the control of generators, bus ties, and distribution feeders. Switchboard instruction books prepared by the various manufacturers provide step-by-step analysis of the operations to be performed with the equipment on specific switchboards and should be consulted in setting up operating routine.

Maintenance of switchboards is largely a matter of the maintenance of individual equipment. Manufacturers' instruction books cover in considerable detail the procedures to be followed in making those adjustments and repairs necessary to correct faulty operation on specific devices. It is therefore sufficient for all practical purposes of this book to outline briefly those maintenance considerations which are of a general nature.

All live parts of a switchboard should be regularly inspected for cleanliness, insulation strength, and tightness of connections. During periods when it is possible to de-energize a switchboard or switchboard section, all connections to power bus work and control connections should be tightened as required. At this time the live parts can be wiped clean of accumulated dust or dirt. Considerable attention should be given toward any accumulation of moisture at or near switchboards. Ventilation ducts and piping should be inspected for leaks as a preventive measure toward this possibility.

Periodic inspection of circuit breakers is recommended. An inspection should always be made after it is known that the breaker has opened a severe short circuit. If the breaker remains open or closed for long periods of time, it is recommended that arrangements be made to open it and close it periodically several times in succession and to clean and lubricate where necessary to keep the contacts and moving parts in good working order.

In general, circuit-breaker mechanisms require very little lubrication, which should be used sparingly. Any excess amount of oil on the breaker parts is apt to collect dust and dirt and is to be avoided. The occasional use of a few drops of a good grade of light machine oil at bearing points is sufficient.

Contacts of type ACB breakers should have rough or high spots removed with a fine clean file or fine clean sandpaper. With type AQB or type NQB breakers, the contacts may be dressed with fine sandpaper.

Meters are extremely delicate instruments which cannot be repaired unless adequate facilities are available. Those facilities are generally provided only on tenders or at shore establishments. Damaged meters are generally replaced with new ones and are turned in for repair.

Most meters, except pyrometers and some special applications, will indicate zero when the equipment is shut down. The procedure for setting a meter to zero is very simple and only requires a small screwdriver. Before adjusting the meter, the case should be lightly tapped with the tip of one finger to help the needle overcome the friction that sometimes exists at the bearings and prevents an otherwise normal unit from coming to rest at zero. When adjustment is necessary, the adjusting screw is slowly turned with the screwdriver until the pointer is at zero.

Relays of the type applied to switchboards for reverse current or reverse power protection are of the induction-disk construction previously described. An operation test and inspection of these relays at least once every 6 months is recommended. Adjustments of pick-up and time delay settings should be made at this time as required.

If the contacts become dirty or slightly pitted, they should be cleaned by scraping the surfaces lightly with a sharp knife or by using a fine, clean, file. Emery or crocus cloth should never be used on the fine silver relay contacts normally furnished with these instruments. The contacts should be finished after scraping by wiping them with a clean soft cloth.

The maintenance on control and instrument switches consists chiefly of the occasional replacement of worn or burned stationary and movable contacts.

CHAPTER 7

DIRECT-CURRENT MOTORS

Operating Principles

There is very little difference in basic construction between a d-c motor and a d-c generator. The generator is rotated by a prime mover to convert mechanical energy into electrical energy, whereas the motor is connected to a source of electric power and converts electrical energy into mechanical energy. Machines designed specifically as generators, however, may be run as motors, and those designed as motors may be run as generators.

Motors operate on the principle that a conductor carrying current in a magnetic field tends to move at right angles to that field. The force that acts on a conductor under these conditions is directly proportional to the strength of the magnetic field, the magnitude of the current, and the length of the conductor.

Since a motor is a rotating machine, the force exerted on the armature conductor is expressed in torque as measured at the motor shaft. This torque for a given motor is therefore directly proportional to the armature current and the strength of the magnetic field.

The horsepower output developed by a motor is a function of its speed and its torque at that speed and is given by the equation

$$P_o = \frac{2\pi NT}{33{,}000}$$

where T = torque in foot-pounds
N = speed in revolutions per minute
P_o = power output in horsepower

The power input to a motor is the product of its terminal voltage E and its line current I or

$$P_i = EI$$

where P_i = power input in watts

Since the efficiency of any machine is the ratio of its power output to its power input, the efficiency of a motor at various loads may be determined from measurements of torque, speed, terminal voltage, and line current.

COUNTER ELECTROMOTIVE FORCE

The armature of a motor is in every way similar to that of a generator. The rotation of its conductors through the magnetic field generates a voltage which is in opposition to the applied voltage, thereby limiting the voltage acting on the armature circuit. The armature current follows Ohm's law and is

$$I_a = \frac{V - E}{R_a}$$

where V = line voltage
E = generated voltage or counter emf
R_a = armature resistance

When a motor is connected directly across the line, its starting current will be limited only by the armature resistance and will reach a value several times normal full-load current. After starting, the counter electromotive force will build up as the speed increases and the armature current will decrease proportionately. For this reason, resistance is generally inserted in series with the line at starting and removed when the motor has accelerated to a sufficient speed for reduction of armature current to a moderate value with full-line voltage applied. This is particularly true on applications involving motors above fractional horsepower sizes where excessive starting currents may result in damage to the motor.

ARMATURE REACTION AND COMMUTATION

Armature reaction is common to both generators and motors. As shown in chapter 3, the armature reaction of a generator causes a distortion in the main field flux that shifts the effective magnetic neutral in the direction of rotation. With motors the armature reaction has the effect of shifting the neutral against the direction of rotation.

In order to secure satisfactory commutation without commutating poles, it would be necessary to shift brushes from the mechanical neutral against the direction of rotation to a point slightly beyond the magnetic neutral established by the load and armature reaction. Brushes in this instance would be set beyond the magnetic neutral instead of exactly at it, in order to counteract the effect of self-induction in the coils being commutated.

Practically all motors installed aboard ship, however, are equipped with commutating poles that neutralize the flux distortion in the neutral plane caused by armature reaction. Commutating poles eliminate the necessity for shifting brushes since armature reaction and the electromotive force of self-induction are substantially neutralized at every load.

Since the flux distortion produced by armature reaction in a motor is in a direction opposite to that produced in a generator, the polarity of the commutating poles in relation to the main field poles is different. In a generator the commutating pole which follows a main field pole in the direction of armature rotation should be of opposite polarity to that of the main field pole, whereas in a motor it should be of like polarity. It is important that this relation be observed when reconnecting the field windings of a motor after extensive overhaul. Polarity should be checked with a compass when the motor is energized for the first time after reassembly.

Shunt Motor

The shunt motor has connections identical to those of a shunt generator, as illustrated in chapter 3. The field is connected directly across the line in parallel with the armature and is substantially constant for all values of load.

The torque and speed of a shunt motor, for all practical purposes, can therefore be considered entirely dependent on the value of armature current since

$$(1)\ \text{torque} = K_1 I_a \Phi$$

$$\text{and (2) speed} = K_2 \frac{V - I_a R_a}{\Phi}$$

where K_1 and K_2 are constants for a particular motor and Φ is the field flux. In a shunt motor K_1, K_2, V, R_a and Φ are all substantially constant, and I_a is the only variable.

When the load on any motor-driven equipment is increased, the developed torque of the motor must increase accordingly, or the equipment will stall. From the equations above, torque is a direct function of the armature current so that a rise in current is necessary to satisfy the new condition. This rise in current is brought about by a decrease in speed that reduces the counter electromotive force and allows more current to flow. Inasmuch as Φ of equation (2) is substantially constant, the reduction in speed from no-load to full-load is, as a rule, comparatively small. For this reason the shunt motor is termed a constant-speed motor, even though there is usually a slight drooping-speed characteristic over the load range.

Speed regulation for constant-speed motors is defined as the *ratio of the difference between rated-load and no-load speeds to the rated-load speed.* This ratio for a shunt motor is usually between 0.02 and 0.06, or 2 percent and 6 percent.

Shunt motors are particularly applicable to engine-room auxiliaries, where it is desirable that the speed be maintained approximately constant. The additional feature of speed control from a shunt-field rheostat makes them also ideally suited to certain pump, blower, and ventilation installations where two or more speeds are required.

Series Motor

The series motor has its field connected directly in series with the armature. This field has comparatively few turns of wire of sufficient cross section to carry the full-load motor current.

The field flux of a series motor may be considered as almost directly proportional to the armature current so that the torque equation

$$T = K_1 I_a \Phi$$

may be reduced to

$$T = K_1 I_a^2$$

Thus, it can be seen from the latter equation that large increases of torque can be obtained in a series motor with moderate increases in current. In actual practice saturation and armature reaction

prevent the torque from increasing as rapidly as the square of the current.

When equation (2) is applied to the series motor,

$$S = K_2 \frac{V - I_a(R_a + R_s)}{\Phi}$$

It is not to be expected that the numerator of this equation will change much more than that for a shunt motor with change in load, but the denominator is nearly proportional to the change in armature current. Hence, the speed of a series motor is practically inversely proportional to the current.

Series motors are dependent on a certain amount of load at all times to keep the speed within safe limits. The loss of mechanical load can cause a series motor to overspeed to the point of destruction. For this reason, series motors are very seldom applied to auxiliaries aboard ship. They do, however, find wide application as starting motors for Diesel and gasoline engines.

Compound Motor

The compound motor is a compromise between the straight series motor and the shunt motor, designed to develop characteristics of speed and torque desirable for certain hoisting applications. With the type of motor ordinarily installed for hoisting duty on a ship, the series field is connected so that its magnetic field is additive to that of the shunt field. A motor connected in this way is known as a *cumulative compounded machine*.

The cumulative compounded motor has a greater speed regulation than the shunt motor, but it has a definite no-load speed and is therefore in no danger of overspeeding when the load is removed. Because of the series field, this type of motor is able to develop high torques with sudden applications of load, making it particularly adaptable to auxiliaries, such as windlasses, winches, capstans, and cranes.

Stabilized Shunt Motors

The modern shunt motor has a small air gap between field poles and armature, which, while reducing the field ampere turns and hence the shunt field losses, has the effect of increasing the armature reaction. Good commutation, nevertheless is secured with the commutating poles, but the high armature reaction reduces the field strength with increasing loads, to the extent that a rising-speed characteristic is developed.

In order to establish a definite speed-drooping characteristic and prevent any possibility of a machine reaching dangerous speeds, a few series turns aiding the shunt turns are wound on each pole. Practically all d-c motors applied on shipboard for constant-speed applications are designed this way and are called *stabilized shunt motors*.

Speed Control of D-C Motors

The inherent characteristics of d-c motors make them decidedly advantageous for application where variable speed is required. On naval ships the range of speed control required for below-deck auxiliaries is ordinarily provided by a shunt field rheostat that changes the field excitation of the motor and hence the value of Φ in the speed equation.

$$S = K_2 \frac{E}{\Phi}$$

where E = counter electromotive force or $(V - I_a R_a)$

An increase in field resistance will therefore result in an increase in speed, and a decrease in resistance, in a reduction of speed.

Speed control for deck machinery where compound motors are applied is obtained by connecting resistance directly in series with the motor armature. This is in effect changing the value of the counter electromotive force and thereby regulating the speed accordingly. A wide range of speed can be obtained by this method, and at the same time the motor will develop any desired torque over its working range, since the torque depends only on the flux and armature current.

The controllers for deck machinery motors employ magnetic contactors for inserting or taking out resistance in the proper sequence to develop several speed steps. These are discussed in some detail in chapter 9.

Dynamic Braking

With applications such as winches, windlasses, and cranes it is necessary to brake the motor when the operation is in the lowering direction and the load is driving the motor. The most effective method is to reconnect the motor so that it acts as a generator and supplies current to a resistance load connected across its armature terminals. The amount of braking applied in this way is determined by the armature current, which is in turn regulated by the value of resistance load.

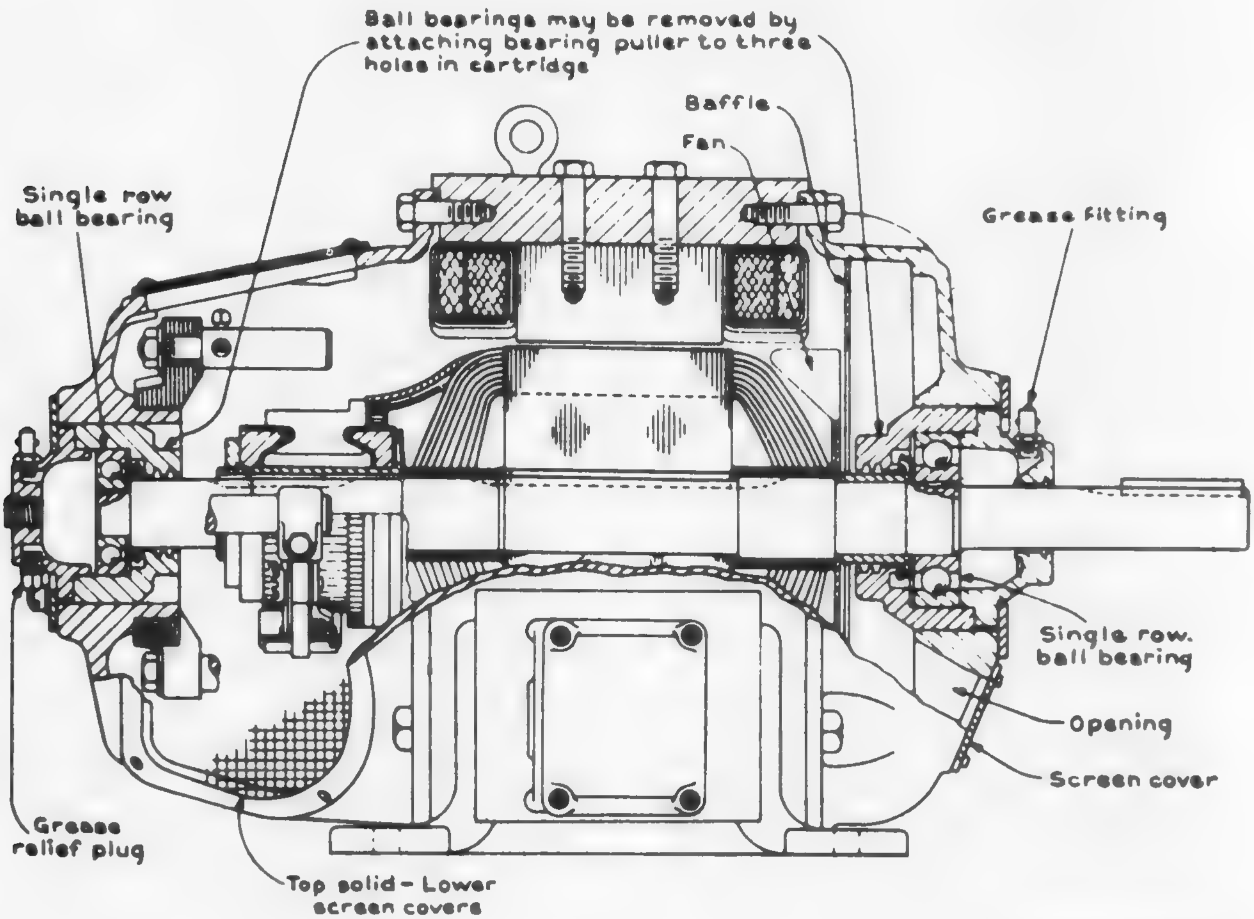
Dynamic braking will not actually stop an overhauling load, since the motor must be rotating to produce any generator effect. It will, however, slow the load down to the point where a mechanical brake can be applied to stop the load smoothly. The mechanical brake on deck-machinery applications is a solenoid- or torque-motor-operated brake and is connected to operate in conjunction with the controller that regulates the hoisting and lowering steps.

Construction

The construction of d-c motors is essentially the same as that described for d-c generators in chapter 3. Generators are ordinarily larger than the motors that drive auxiliaries, and on the smaller machines there are minor differences relative to end-bracket construction, bearings, methods of securing armatures and commutators, and the general over-all appearance of the machine.

In this discussion a medium-size motor will serve to illustrate the general construction common to most d-c motors for below-deck auxiliaries. Such a motor is shown in the assembly drawings of figure 86.

The frame of the motor is made from a single rolled-steel plate. Drop forged or fabricated mounting feet are welded to this frame.



Courtesy of General Electric Co.

Figure 86.—D-c motor for below-deck auxiliaries.

Ball bearings are generally provided on small- and medium-sized motors. Bearing housings have a seal that prevents leakage of grease from the bearing into the motor, and also prevents the entrance of water. Grease is applied through a grease pipe at the top of the bearing housing. A drain plug is fitted on the underside of the housing.

In briefly describing ball-bearing motors some mention should be made of the sealed-in life type of ball bearing now used on shipboard motors. These bearings are designed with a cartridge-type enclosure so as to eliminate the need for greasing by operating personnel.

Armature construction is of the conventional laminated-core design with spacers that form longitudinal air ducts for ventilation purposes.

Commutator bars follow the same dovetail-shape design as previously described for generator commutators. These bars are held rigidly in place by the wedging action of the commutator bushing and commutator ring, with the assembly secured into position by the commutator nut.

Shunt and series coils are wound on a common field piece, but they are generally arranged so that each coil may be removed as a unit when it is necessary to make replacements. Field pieces are secured to the frame by various methods, one of which is to pass two bolts through the field piece and tap them into the frame.

Brush-holder rods are mounted on a rocker ring or are mounted as a part of the end bracket. With either arrangements the brushes may be shifted for adjustment of commutation. With the former construction the rocker ring is moved; this operation moves all brush rods and brush-holders simultaneously.

The same result is accomplished in the latter construction by turning the end bracket.

Motors in the larger horsepower ratings are fitted with fans or blowers mounted on the opposite end of the shaft from the commutator. These fans generally draw the air in at the lower rear bracket and exhaust it out of the front bracket.

Motors for deck machinery, such as are ordinarily installed on auxiliary supply ships for cargo winches; windlasses, and capstans, are generally of the type used on merchant ships and do not necessarily correspond to Navy specifications for weathertight motors.

They are designed for service requiring heavy overload capacity and quick-starting, stopping, and reversing characteristics. The construction relative to frame, shafting, and armature is more rugged than that of below-deck auxiliary motors. Frames are generally of cast-steel construction and are split into two halves to permit removal of the top half for inspection and maintenance. There is a shaft extension on each end, with one shaft designed for connection to the load and the other for connection to the brake wheel of a solenoid- or torque-motor-operated brake.

Degree of Enclosure

The degree of enclosure of a motor is generally expressed in terms of its ability to withstand conditions imposed by weather, moisture, water, or atmospheres that may be of an explosive nature. The type of enclosure is therefore determined by the location aboard ship where the motor is to be applied. Bureau of Ships Specifications 17M17, dated January 23, 1949, defines the major types of enclosures as follows:

1. *Drip-proof.*—In a drip-proof motor the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine at an angle not greater than 45 degrees from the vertical cannot enter the machine either directly or by striking and running along a horizontal or inwardly inclined surface.

2. *Splash-proof.*—In a splash-proof motor the ventilating openings are so constructed that drops of liquid or solid particles falling from the vertical on the enclosure or coming toward it in a straight line at any angle not greater than 100 degrees from the vertical cannot enter the enclosure directly or by striking and running along the surface.

3. *Watertight.*—A watertight motor is so designed and constructed that it will exclude water when submerged in water up to a 15-foot head.

4. *Explosion-proof.*—An explosion-proof motor is so designed and constructed as to withstand without injury and explosion of gasoline vapor or other specified gas or dust occurring within it and to prevent ignition of gas or dust surrounding the enclosure, by sparks, flashes, explosion or flame transmitted from within.

5. *Submersible.*—A submersible motor is so designed and constructed that unless otherwise specified it will withstand submergence in standard sea water under a pressure equivalent to a 50-foot head for a period of 1 hour without evidence of leakage.

Insulation

The insulation of shipboard motors is divided into three classes pertaining to temperatures to which they may be continuously subjected and still perform satisfactorily throughout normal life expectancy. The classes are termed "A," "B," and "H" and the maximum temperatures they can withstand are progressive in that order as follows:

Class	*Degrees C*
A	105
B	130
H	No limit has yet been selected

The various organic and inorganic materials used to make up each class are specified in Bureau of Ships Specifications.

Operation and Maintenance

OPERATION

The actual operation of motors is normally a matter of pushing the "Start" or "Stop" button of a master control switch or manipulating the handle on a master switch designed for multispeed operation. A good operator, however, is alert to observe indications of trouble in a motor under conditions of starting, running, and stopping. He is also careful to examine the motor closely before starting for assurance that it is in running condition. The thoroughness of this examination will depend to some extent on how long the motor has been secured.

A routine check prior to starting a motor after a short period of shutdown includes observance that covers and guards are in place and that no one is working on the motor or equipment which it drives.

After an extensive period of shutdown, inspect a motor for the following conditions before starting it:

1. All mechanical fastenings are tight, particularly such rotating parts as the armature, commutator, and fan.

2. All accessible internal and external electrical connections are tight, with no visible evidence of damaged insulation or inadequate clearance distance between conductors of different polarity and between conductors and ground.

3. The air gap between the armature and field poles is maintained throughout the complete revolution of the armature.

4. The bearings are in good condition as indicated from inspection without disassembly. Lubricant appears to be clean and in proper quantity, and oil rings are free to turn.

5. The motor is free from excessive dirt, foreign matter, and extraneous material.

6. The entire rotor assembly of motor and driven equipment is free to turn.

7. The brushes and the commutator appear to be in good condition, with brush holders securely held in the neutral position by the rocker arm or end bracket.

8. Insulation resistance as measured is satisfactory.

9. Equipment driven by the motor is ready for operation.

While a motor is running, its operation should be occasionally checked.

Whenever there is doubt concerning the temperature of a bearing, the actual condition should be determined by a thermometer attached to the bearing housing by means of putty and friction tape. Smoke and the odor of hot grease issuing from a bearing are, of course, positive indications of excessive temperature. The safe-maximum operating temperature is generally 80° to 95° C.

It is very important to make an occasional check of commutation on d-c motors. There should be practically no visible sparking, but small blue pin sparks are not considered harmful. In normal operation the commutator will take on a dark color but will become highly polished. When harmful sparking is occurring, it will be evidenced by a burning and pitting of the commutator surface.

Vibration or excessive noise is usually quite evident to personnel in the working space, when such conditions are recognized, immediate steps should be taken to remove the equipment from service and to investigate the source of trouble.

If, when the hand is placed on the motor frame, the motor appears to be running at a higher temperature than normal, it should be checked more carefully with thermometers. The insulation temperature is of primary concern, and if practicable the thermometers should be placed directly on field coils, stator coils, and armature coils. Whenever

possible, several thermometers should be used at different placed on the coils in order to determine the maximum temperature. Thermometers should be wired or taped in place to keep them from being vibrated out of position. The thermometer bulb should be held in contact with the winding by welders' putty, or surgical adhesive tape. The temperature of rotating parts cannot be measured until the motor has been stopped, but all preliminary preparations should be made to put thermometers quickly in place as soon as the machine comes to rest.

Temperature of windings may also be measured by the resistance method if suitable instruments are available to secure accurate measurements of cold and hot resistance. Cold resistance is measured after the motor has been secured for a considerable period of time and temperatures inside the motor correspond to ambient. Hot resistance is measured after the motor has been allowed to run for a suitable length of time under load. Several readings of hot resistance should be taken in order to determine the maximum value. The temperature corresponding to the hot resistance is computed from the formula

$$th = \frac{Rh}{Rc}(t_c + 234.5) - 234.5$$

where th = temperature hot
t_c = temperature cold
Rh = Resistance hot
Rc = resistance cold

MAINTENANCE

When certain abnormal operating conditions are revealed from inspections during starting and running, secure the equipment and make a diagnosis of the trouble. Some of the more common causes of faulty operation are as follows:

1. Poor commutation:
   a. Incorrect brush position.
   b. Poorly fitted or worn out brushes.
   c. Rough commutator.
   d. Short circuit in armature.
   e. Overload.
   f. Brushes tight in the holders.
   g. High mica on the commutator (should be undercut 1/32").
2. Overheating:
   a. Overload on motor.
   b. Short circuit on one or more armature coils.
   c. Grounded circuit resulting in a short circuit drawing heavy current to ground.
3. Hot bearings:
   a. Bent shaft.
   b. Misalignment of motor and auxiliary.
   c. Lack of grease or too much grease for ball or roller bearings. With sleeve bearings not enough oil, dirt in oil, or oil ring stuck or rotating too slowly.
   d. Broken bearing or dirt in bearing.
   e. Rubbing of bearing cap with resultant scoring of the shaft.
4. Vibration:
   a. Unbalanced armature or misalignment between motor and driven machine.
   b. Rubbing of the armature on a pole piece, loose footing, or poor brush adjustment.

The maintenance of d-c motors follows similar procedures as outlined for d-c generators in chapter 3. It should be pointed out, however, that some of these procedures that are a part of ships' routine for generator maintenance are often overlooked in servicing motors. The performance of a motor is no better than that of a generator unless comparable maintenance methods are used.

Many motor troubles can be traced to lack of cleanliness. Dust and dirt invite the collection of moisture, grease, and fumes that attack insulation. Frequent cleaning also serves to expose small defects which may be corrected before they develop into serious damage. Motors may be cleaned aboard ship by wiping or by blowing out with compressed air. Carbon tetrachloride or similar solvent can be used for cleaning insulation in extreme cases, but a dry rag is usually sufficient to remove most dirt.

The lubrication of ball bearings is a very important consideration in keeping motors in good running condition. A sufficient amount of lubricant to maintain a film over the surfaces of the balls and races is essential. Too much grease, however, will cause overheating and grease leakage. The increase in temperature will generally be temporary and will not be harmful; but if it persists more than 4 or 5 hours, or is excessive, some of the grease should be removed from the bearing.

When grease drippings from the drain plug indicate that the grease is contaminated with dirt or grit, a complete flushing out of the bearing should be performed, using carbon tetrachloride or a similar solvent. The bearings should then be

repacked with grease in the prescribed manner.

Sealed-in life bearings require little or no attention over a period of from 3 to 5 years. Generally, when faulty operation is indicated, a bearing will require replacement.

When a motor with oil ring bearings has operated a week after initial installation, the oil should be drawn off and kerosene or fresh oil should be poured through the bearings to wash out sediment. The bearings should then be refilled. In normal service, bearings should be washed out and refilled at regular intervals (at least once a year), depending on the length of service, temperature, and cleanliness. Oil should be drained off and replaced with fresh clean oil about every 60 days.

Maintenance procedures for brushes, commutators, field poles, and armature windings are covered in some detail in chapter 3 and should be referred to in summing up the major considerations of motor maintenance.

CHAPTER 8

ALTERNATING-CURRENT MOTORS

Operating Principles

Squirrel-Cage Induction Motors

Alternating-current motors are built in a variety of designs to meet the performance requirements of different applications. The greatest proportion of motor horsepower load on a ship's a-c power distribution system, however, is made up of three-phase squirrel-cage induction motors. For this reason the major portion of this discussion will be confined to this type of motor.

Rotating Magnetic Field

The stator of an a-c motor is wound in the same manner as an alternator stator to produce a series of field poles around the inside periphery. If excited with direct current, the poles of a stator will be found to be alternately north and south. When excited with alternating current, each pole will change its polarity at a rate equal to twice the frequency of the supply. This is in effect advancing north and south polarities around the stator at a speed which, when evaluated in terms of revolutions per minute, becomes

$$N = \frac{60 \text{ x } 2f}{P}$$

where N = speed of rotating field
f = frequency in cycles per second
P = number of poles

The operation of any motor depends on the interaction of stator and rotor fields, which develops the force necessary to turn the rotor. The rotor of an induction motor has no electrical connection with the power supply and depends for excitation on currents induced in its conductors by the rotating field. While the rotor tends to follow the rotating field, its speed must necessarily be lower, since the induced currents are dependent on a relative speed existing between the rotor and the stator rotating field.

The difference between the speed of the rotating field and that of the rotor is called the slip of the motor. Thus, for example, if a 6-pole, 60-cycle motor has a speed of 1,150 revolutions per minute, its revolutions slip is 1,200–1,150 = 50 revolutions, per minute, where 1,200 revolutions per minute is the speed of the rotating field, or synchronous speed. Slip is generally expressed as a percentage of synchronous speed and is calculated from

$$S = \frac{(N - N_1)}{N} 100$$

where S = percent slip
N = synchronous speed
N_1 = speed of the motor

Slip is a minimum at no load and increases as load is applied.

It follows from the above that the frequency of currents induced in the rotor circuits increases as the slip increases, so that

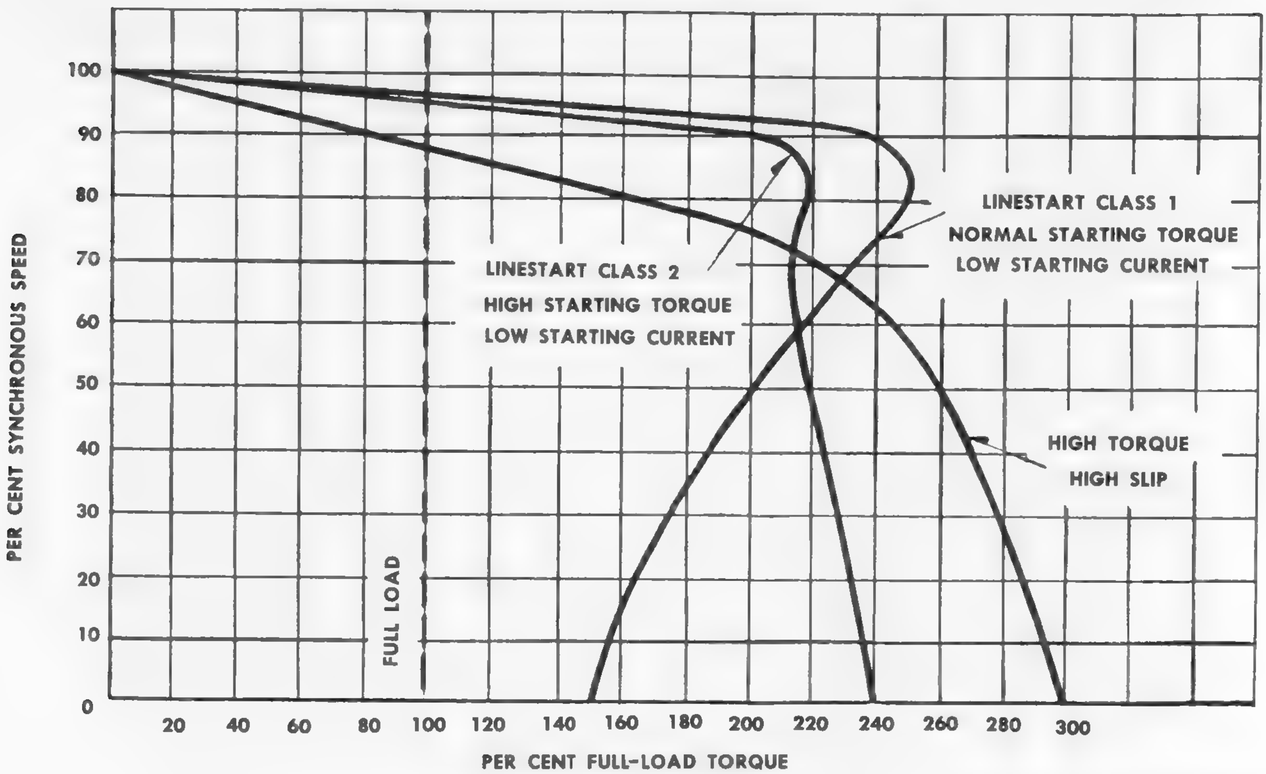
$$f_2 = Sf/100$$

where f_2 = rotor frequency
f = synchronous speed

Rotor reactance is a function of the rotor frequency and rotor inductance, or

$$X_R = 2\pi f_2 L_R$$

where X_R = rotor reactance
L_R = rotor inductance



Courtesy of Westinghouse Electrical Corp.

Figure 87.—Squirrel-cage induction-motor characteristic curves.

At low values of slip the rotor currents lag the induced electromotive force by a small angle so that they are in approximate time phase with the air-gap flux. Under this condition the maximum value of torque is developed for a particular value of current, since the maximum values of rotor current practically coincide with the maximum values of air-gap flux density.

With increase in slip and increase in rotor reactance, there is an added time phase difference between rotor currents and air-gap flux so that the torque is correspondingly reduced over what it would be at a lower value of slip. At large values of slip the torque may be small, even though the rotor current is large.

The torque of a motor must always balance the torque required by its mechanical load, or the motor will stall. Increase in load on an induction motor is accompanied by an increase in rotor current with a corresponding increase to the current of the power supply. There is also an increase in slip and a decrease in rotor power factor, so that the effectiveness of the rotor current in producing increased torque is partially offset by the increased time-phase difference between current and air-gap flux.

An induction motor will develop a maximum value of torque at a certain mechanical load above the full-load rating of the motor. Beyond this point, an increase in slip is accompanied by a decrease in torque, and the motor becomes unstable. This value of maximum torque is called the breakdown torque, since the motor will stall if subjected to sustained loads which require a greater amount of torque.

The breakdown, or maximum torque varies as the square of the voltage and inversely as the stator impedance and rotor reactance. It is independent of the rotor resistance except that the rotor resistance determines the speed at which maximum torque occurs.

Squirrel-cage motors are designed with varying resistances, depending on the amount of torque required at starting. Obviously the amount of torque available at starting will depend on the power factor at 100 percent slip, which can be

increased to a point where the maximum, or breakdown, torque occurs at starting. A motor designed in this manner can never pass the point of instability, and it is suitable for starting heavy loads under intermittent service conditions where a comparatively low efficiency due to I^2R losses is not important and where high slip is not objectionable.

Most of the squirrel-cage induction motors used aboard naval ships have rotor resistances which are a compromise between good starting characteristics, low slip, and high efficiency. These are known as *general-purpose motors* and are used to drive pumps, blowers, ventilation fans and numerous other auxiliaries where the starting torque is not required to be in excess of about 150 percent of full-load torque. The starting current of these motors is from four to six times normal, and with motors of 25 horsepower and above, reduced-voltage starting is generally employed to reduce the starting current. High-capacity installations with improved voltage regulators allow motors of more than 100 horsepower to be started across the line. (See chapter 9.)

Another type of design makes it possible to have a high-starting torque and yet have a fairly high efficiency and low slip at running speeds. This design utilized rotor bars of a special shape. Each bar is shaped to have a high-resistance portion close to the rotor circumference and a low-resistance portion in the inner portion of a deep slot. The inner portions of the bars link more flux and have a high reactance at starting rotor frequency. This reactance at starting causes most of the rotor current to flow in the outer resistance part of the rotor bars so that a high-starting torque is developed. At running speed the reactance of the inner part of the bars is reduced, permitting more current to flow in that part of the rotor. This reduces the value of effective resistance, permitting high efficiency and low slip at running speeds.

To illustrate the performance of the three types of squirrel-cage motors discussed above, characteristic curves are given in figure 87.

Two-speed Squirrel-Cage Motors

Motors with more than one speed are required for some applications on naval ships, including ventilation fans, certain pumps, elevators, and hoists. Most of these applications require only a motor which can deliver two rated speeds.

The ordinary squirrel-cage motor is fundamentally a single-speed motor, since its speed is effected only by the frequency, slip, and number of poles, as given in the equation.

$$N_2=\frac{f.120}{P}(1-S/100)$$

where N_2 = motor speed

Two different speed ratings can, however, be obtained by having a stator winding which can be reconnected to change the total number of poles. Manufacturers have devised several schemes of accomplishing this with a single winding whereby a high speed and a low speed in the ratio of 2 to 1 can be obtained. Where the speed ratio is 2 to 1, a single "consequent pole" stator winding is generally used. The leads of the two-speed single-winding motor can be connected in such a way as to obtain one of the following characteristics at both high and low speeds: constant torque, variable torque, or constant horsepower.

For any speed ratio other than 2 to 1, a separate stator winding is required for each speed. Each winding of a two-winding motor is designed to produce the required number of poles to develop one of the rated speeds. The motor control for this type of motor is arranged to connect one or the other of these windings to the line, depending on the speed selected by the operator.

Wound-Rotor Motor

The *wound-rotor induction motor* is similar to the squirrel-cage motor with the exception that the rotor circuit is made up of individually insulated coils which are connected to slip rings. Through brushes which ride on the slip rings, external resistance can be added to or taken out of the rotor circuit for adjustment of speed and torque.

A few wound-rotor motors are installed aboard naval ships where it is necessary to have high-starting torques and several steps of speed control. Typical applications include snubbing winches and stern capstans.

In addition to a more complicated design than the squirrel-cage motor, wound-rotor motors require numerous control devices to accomplish their function and are therefore not practical for most applications.

Synchronous Motors

In chapter 3 on a-c generators it was pointed out that when two alternators are operating in parallel

and the mechanical driving power of one machine is removed, this machine will operate as a motor until removed from the line by a protective reverse power relay. Under these conditions the stator is receiving power from the bus and the d-c excited rotor locks in step with the rotating magnetic field of the stator. The alternator now operates as a *synchronous motor*, since the rotor revolves at the same speed as the stator field, and mechanical torque is delivered to its shaft.

With one exception synchronous motors and alternators are similar in construction. The former are generally equipped with an auxiliary squirrel-cage winding that permits operation as an induction motor until a speed is reached where the rotor can be separately excited and pulled into step with the stator field.

As load is applied to a synchronous motor, the center of each rotor pole takes up a position of increasing lag with respect to the center of poles formed by the rotating field of the stator. This is analogous to a spring tension existing between rotor and stator with a stretching of the spring as mechanical load is applied. It is this increasing rotor lag that causes more current to be drawn from the line as load is applied.

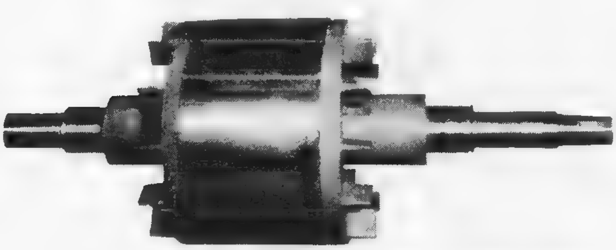
There is a limit to the amount of lag that can exist between rotor and stator before the machines will fall out of step and stall. The torque required to cause the breakdown point is called the *pull-out torque*.

A very desirable characteristic of synchronous motors is the fact that their power factor can be varied over a wide range by merely changing the field excitation. When operating overexcited, they draw leading current from the line and thereby help to improve the power factor of the system. Thus it would appear that their application aboard ship would be advantageous to compensate partially for the heavy inductive load imposed on the system by induction motors. The simple construction of the squirrel-cage motor, however, and the necessity of d-c excitation for the synchronous motor decide in favor of the induction motor for the majority of a-c installations. Furthermore, the synchronous motor requires a more complicated starter than the squirrel-cage motor.

Synchronous motors are sometimes used in connection with a-c and d-c motor generator sets. They are also applied on electric propulsion installations to drive low-speed propeller shafts. (See chapter 12.)

Construction

To gain the best electrical performance from squirrel-cage induction motors, the air-gap between rotor and stator is made as small as possible. With a small air gap, it is essential that all mechanical parts be firmly held in position within close tolerances. On naval vessels where motors are apt to be subjected to high-impact shock, the construction must be extremely rugged to maintain the relative position of rotating and stationary parts.



Courtesy of General Electric Co.

Figure 88.—Squirrel-cage rotor with cast bars and rings.

The basic parts of a squirrel-cage motor consists of the stator, rotor and shaft, end shields and bearings.

The stator frame holds a core of slotted sheet-metal punchings, which are tightly compressed to form a laminated assembly. This assembly is keyed or welded to the inside of the frame. The frame itself is a cylindrical shape that is fabricated from rolled-steel plate, with mounting feet and terminal connection box welded to the outside periphery. Stator windings are similar in design to those of alternators, and for motors in the integral horsepower ratings these windings utilize form-wound coils which are inserted into the stator slots.

The rotor is keyed to a steel or monel metal-shaft and consists of a laminated sheet-steel core into which are imbedded the rotor bars or squirrel-cage winding. The squirrel-cage winding of many motors is aluminum or similar metal cast into the slots of the core. Short-circuiting rings are integral with the casting, and ring projections form fan

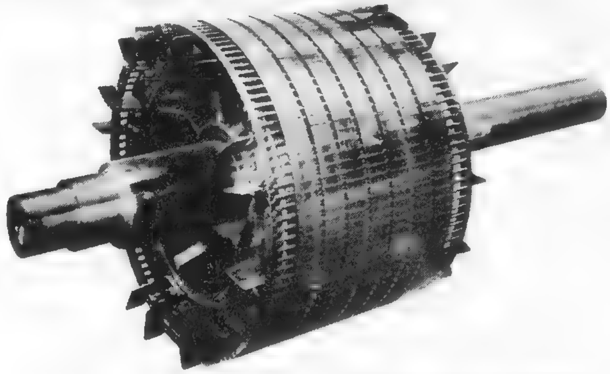
blades for ventilating the motor. An assembled rotor and shaft is shown in figure 88.

Other types of rotors have a winding made up of longitudinal bars in slots just below the outer surface of the rotor. Copper rings are brazed to the bars at each end of the rotor. This type of rotor is illustrated in figure 89.

Monel-metal shafts are used in place of steel shafts for motors that are close-coupled with pumps and are subject to water corrosion.

End bells are generally made of steel to withstand the high-impact shock tests to which all shipboard motors must be subjected. The bells fit into accurately machined shoulder joints around the periphery of the stator frame and are held in place by cap screws, studs, or bolts.

Practically all small- and medium-size motors are equipped with ball bearings. These bearings can absorb thrust loads and with their grease lubrication are not adversely affected by changing position owing to the motion of a ship. As described in chapter 7, grease cups are provided on the top of the bearing chambers with a relief drain plug on the lower side of the bearing housing.



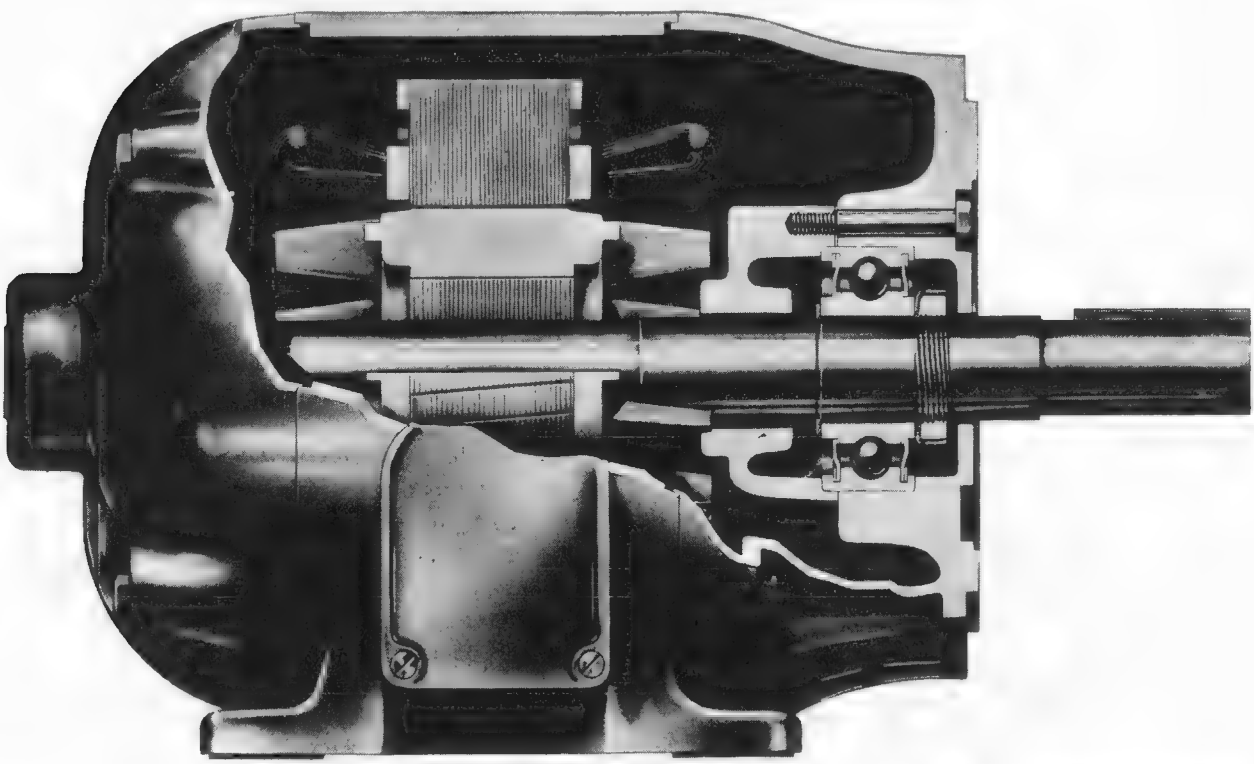
Courtesy of General Electric Co.

Figure 89.—Squirrel-cage rotor with brazed bars and rings.

A cutaway view of an assembled motor is shown in figure 90.

Motor Enclosures

The degree of enclosure provided with a-c motors is determined in the same way as that for d-c



Courtesy of Westinghouse Electrical Corp.

Figure 90.—Cutaway view of assembled squirrel-cage motor.

motors; that is, the location aboard ship where the motor is to be applied. The construction of the a-c motor greatly simplifies the problem of enclosure for splashproof, watertight, and submersible motors, as compared with that for d-c motors.

Insulation

The insulation of stator windings must be designed to withstand the temperature conditions imposed by the space in which the motor is located, as described in chapter 7.

Operation and Maintenance

A-c motors require the same general care to keep them in good operating condition as outlined for d-c motors in chapter 7. All precautions relating to bearing lubrication, winding temperatures, and alignment with driven equipment, as listed in that chapter, are equally applicable with a-c motors and do not require repetition.

Squirrel-cage rotors with cast aluminum bars and end rings are extremely rugged and are subject to little or no electrical troubles. Rotors made up of copper bars brazed to copper end rings are subject to open circuits or high resistance points between the end rings and rotor bars. The symptoms under these conditions are similar to those expected with wound rotors where there is a slowing down under load and reduced-starting torque.

Such conditions can usually be spotted by the evidence of heating at the end-ring connections after a shut down from full-load operation. Any fractures in rotor bars will usually be found either at the point of connection to the end ring or at a point where the bar leaves the laminations. Excessive heating is also evidenced by discolored rotor bars.

It has been stated that a small air gap is characteristic of induction motors. The air gap should be checked periodically with a feeler gauge to insure against a worn bearing that might permit the rotor to rub the laminations of the stator. If some record is made of these measurements, a comparison between sets of readings will give an early indication of bearing wear.

CHAPTER 9

MOTOR CONTROL

Control Applications

The discussion in this chapter is confined to controls associated with motors, since this is the principal type which engineering officers encounter on board naval vessels. Other types of controls follow the same principles of operation and can be easily analyzed after the student has familiarized himself with the principal motor-control applications.

The following terms and symbols are defined as a preparation for the study of the various control applications commonly installed aboard ship:

A *contactor* is a device for repeatedly closing and interrupting an electric power circuit.

A *relay* is a device that operates with variations of the electric circuit in which it is connected, to affect the operation of other devices.

A *starter*, or *controller*, is a device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the motor to which it is connected.

A *manual starter* or *controller* is one in which the contacts normally used to energize and de-energize the connected load are closed and usually opened through a mechanical system directly actuated by an operator.

A *magnetic controller* is one in which the contacts normally used to energize and de-energize the connected load are closed by electro-mechanically operated devices. Such a controller is generally operated from a push button or pilot switch.

A *contactor*, or *relay armature*, is that movable part of the magnetic circuit that closes or opens the contacts when the coil circuit is energized.

An *across-line-starter* throws the connected load directly across the main supply line.

A *master switch* is a device that governs the electrical operation of a starter or controller.

A *manual master switch* is actuated by an operator to have its contacts opened or closed.

An *automatic master switch* is one that is operated by the effect of physical forces (for example, float, limit, and pressure switches).

A *momentary-contact master switch* is one in which the contact is closed or opened against spring action to start a series of operations and then returns to its original position.

A *maintaining-contact master switch* is one in which the contact is closed or opened to start a series of operations and does not return to its original condition until again actuated by an operator.

A *contact* is that part of a control device, such as a relay, master switch, or contactor, that establishes or interrupts the electric circuit.

An *auxiliary contact* is a contact attached to a main contactor that is used in the control circuit to energize or de-energize other devices when the main contactor closes or opens.

A *resistor* is a device that is used to increase the resistance in an electric circuit.

A *rheostat* is an adjustable resistor whose resistance may be changed without opening the electric circuit in which it is connected.

Normally open or normally closed when applied to contacts and interlocks of control devices, such as contactors, relays, and master switches, indicates the position taken (open or closed) when the control device is de-energized. The de-energized condition for a manual controller is considered the "off" position.

Symbols

	contact normally open
	contact normally closed
	overload relay (thermal type)
	overload relay contact
	momentary-contact push button normally open
	momentary-contact push button normally closed
	momentary-contact push button with two sets of contacts, one normally closed and one normally open
	maintaining-contact push button
	pilot switch (pressure, float, etc.)
	contactor, or relay coil (letter inside circle to suit)
	fuse
AL_1 CL_3 BL_2	incoming-power lines
AT_1 CT_3 BT_2	power supply to motor
	resistor, fixed-type
	resistor, adjustable-type
	field rheostat

The discussion of switchboards has shown the necessity for protective controls in electric circuits to prevent damage to generators and cable when short circuits or excessive overloads occur. All motors with the exception of small fractional horsepower sizes are connected to the line through a starter, which includes a line-switch and a protective circuit interrupting device. The simplest form of protective control is an ordinary fused knife switch, which is, however, rarely used in shipboard applications. This form of control is designed to protect only the generating and distribution equipment against short circuits.

Modern control apparatus is designed to broaden the field of protection by protecting the motor, as well as the generator and distribution equipment. The device most commonly used for motor protection is the *thermal-type overload relay*. A typical relay of this type has a heater coil connected in the motor power circuit which, when sufficiently heated by overload currents, will cause a bimetallic strip to expand and electrically or mechanically disconnect the motor from the line. Thermal-type relays are designed to heat up at the same rate as the motor and thus remove the motor from the line before serious overheating occurs. Momentary overloads do not ordinarily produce sufficient heating effect to overheat a motor or operate the thermal overload relay.

The motor power circuit making and interrupting device is manually or magnetically operated, depending on the size of motor and its application. When thermal-bimetallic-type overload relays are used with manual starters, the main-line contactors are usually closed manually against a spring with a latch support. The thermal strip contained in such relays deflects when overheated and releases the latch that supports the spring.

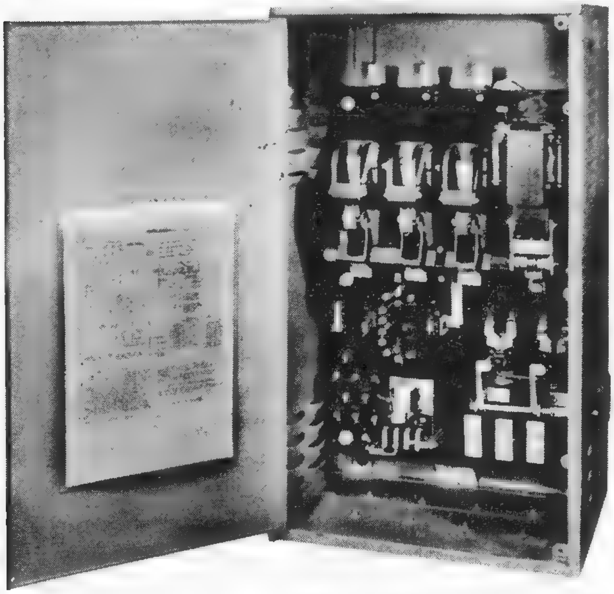
Magnetically operated starters use contactors which are generally opened or closed by means of electro-magnetically operated devices. Overload relays used in this type of control are usually arranged to open the contactor coil circuit. When the contactor is de-energized, it is opened by the force of a spring and disconnects the motor from the line.

Alternating Current Motor Starters

Across-the-Line Starter

The most common type of motor starter used on ships with a-c supply connects the motor directly to the line without any intermediate steps of starting resistance or other voltage-reducing equipment. This is commonly known as the *across-the-line starter* and may be of the manual or magnetic type, depending on the horsepower rating of the motor.

This type of starting may be used with the squirrel-cage induction motor of average size because of the simple design and rugged construction



Courtesy of Westinghouse Electrical Corp.

Figure 91.—Across-the-line starter.

of this motor and its ability to withstand without damaging effect the high inrush currents caused by starting with full-line voltage applied. The majority of squirrel-cage motors, which drive pumps, compressors, fans, and other below-deck auxiliaries, are within the range that permits across-the-line starting without producing excessive line-voltage drop or prohibitive mechanical shock to the motor or driven machinery.

The typical three-phase across-the-line starter consists of a three-pole main-line contactor, two overload relays, mounting panel, an enclosure with mechanical overload-relay reset mechanism, and a master switch. The generl appearance of this type of starter is shown in figure 91.

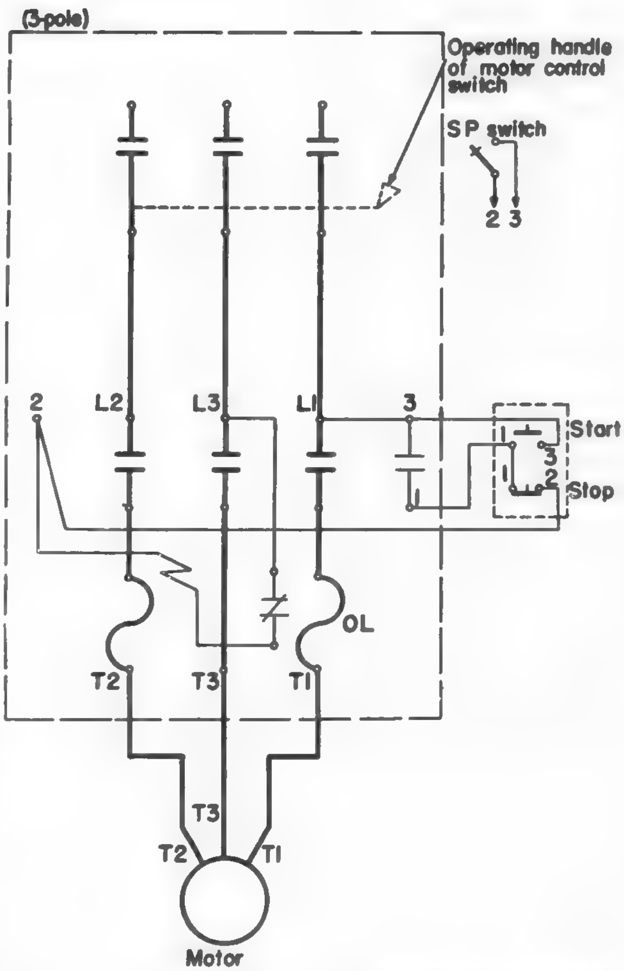
The wiring diagram of figure 92 shows the connections between the elements of the starter, the starter and push-button station, and the starter and motor. Heavy lines represent the wiring which actually carries motor current, and the light lines represent wiring for control.

The three line contacts, the auxiliary contact, and the coil are all parts of the contactor assembly, which operates to close all contacts when the coil is energized and to open them when the coil is deenergized. A detailed description of typical contactors follows in the section on control devices.

The overload relay *OL* consists of two heating coils and a single normally closed contact in one assembly. This contact can be opened by the action of either heating coil.

For simplicity in the analysis of control circuits, connection diagrams are generally reduced to a simplified form, known as elementary wiring diagrams. An elementary diagram is shown in figure 93.

Connections are numbered in the control circuit to simplify checking of the diagram with the connection diagram or, in practice, with actual connections on the control panel. Equipment connections, are identified by terminal markings on either



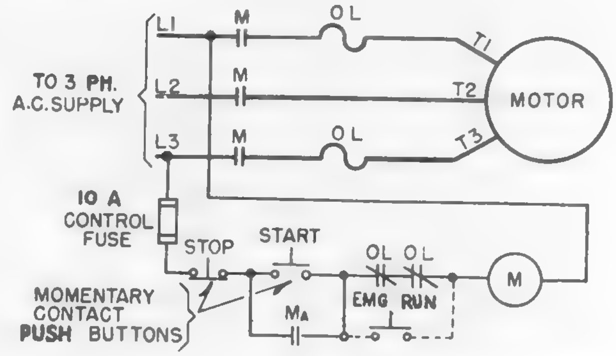
Courtesy of General Electric Co.

Figure 92.—Connection diagram for magnetic across-the-line starter with low-voltage protection.

the control devices or the panel on which the control devices are mounted.

In figure 93 observe that a circuit is initially completed to the main-line contactor coil through the "Start" and "Stop" buttons and the overload-relay contacts. Thus, with the operation of the "Start" button the *M* coil is energized and immediately closes the *M* contacts, connecting the motor directly to the line. The auxiliary contact *Ma* is an integral part of the main contactor and closes when the *M* coil is energized. It is connected across the "Start" button to permit the coil *M* to remain energized after the "Start" button has been released. The motor will therefore remain connected to the line unless the control circuit is opened by either the "Stop" button, the *OL* contacts, or a reduction of line voltage to a value insufficient to hold the main contactor closed.

The overload-relay contacts are opened by action of either of the heater coils in the power circuit when the load on the motor becomes excessive. Two sets of coils are provided for protection against single-phase operation of the motor, a condition that could arise for example, when a main contact becomes faulty in operation. After operation of the thermal-type overload relay it is necessary to wait until the heater coils cool down before the relay can be manually or automatically reset and the motor restarted with the "Start" push button. Some overload relays must be reset manually, whereas others automatically reset themselves.



Courtesy of Westinghouse Electrical Corp.

Figure 93.—Elementary wiring diagram for magnetic across-the-line starter with low-voltage protection.

If the main contactor drops out because of an excessive drop in line voltage or a power failure, the motor will remain disconnected from the line until an operator restarts it with the "Start" push button. This prevents automatic restarting of equipment when normal power is restored, a condition which can result in injury to personnel. For this reason the term *low-voltage protection* is applied to the type of starter shown in figures 92 and 93.

Low-Voltage Release

Magnetic across-the-line starters are furnished with a variety of control circuits designed to provide the protection required and the method of starting best suited to the application. The following discussion describes other control circuits most com-

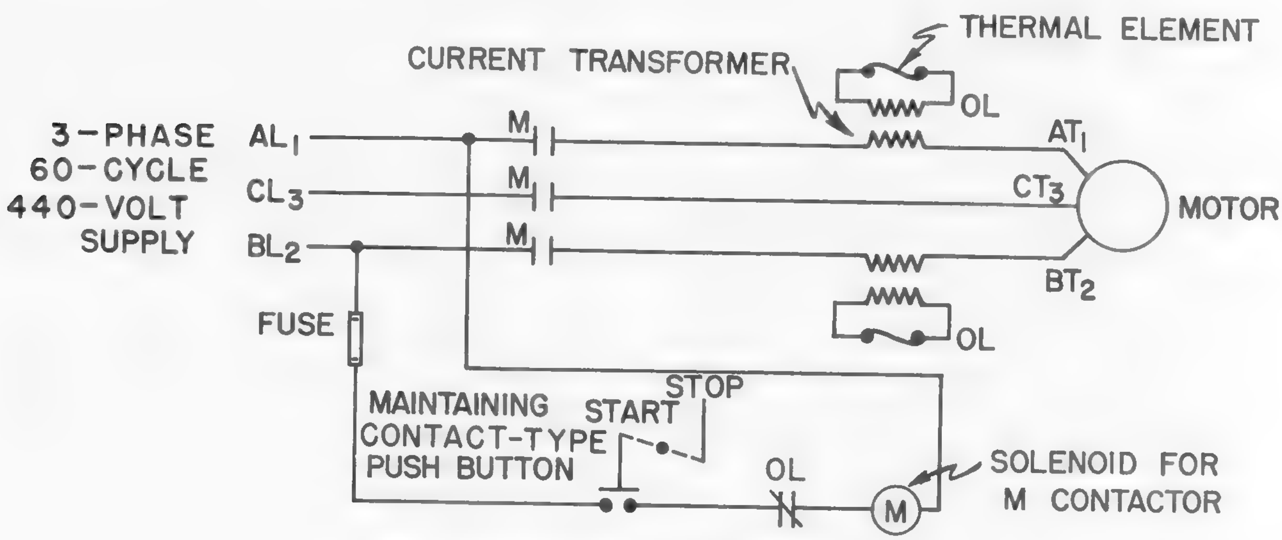


Figure 94.—Across-the-line starter with low-voltage release.

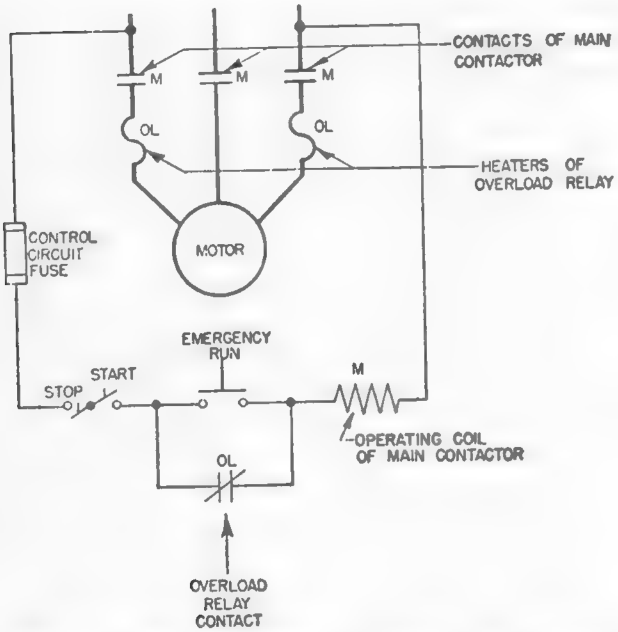


Figure 95.—Elementary diagram of controller with emergency run feature by separate push button.

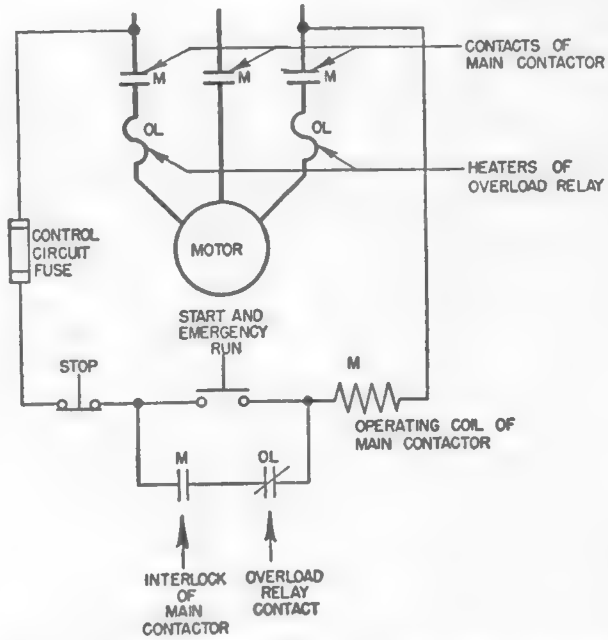


Figure 96.—Elementary diagram of controller with emergency run feature at "Start" button.

monly installed aboard naval ships with a-c power supply.

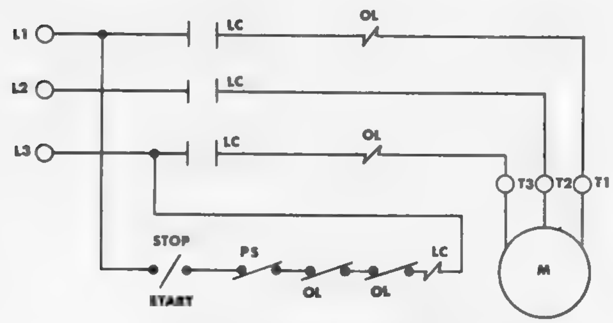
The control circuit of figure 94 utilizes a maintaining-contact push-button station having a single set of contacts that are closed by pressing the "Start" button and remain closed until opened by pressing the "Stop" button. The contactor *M* is energized when the "Start" button is pressed, and the motor is connected directly to the line. Under conditions of excessive voltage drop or power failure the *M* contactor will drop out, but it will be automatically re-energized when normal power is restored. This reconnects the motor to the line without the attention of an operator. This feature is known as *low-voltage release* and is restricted to auxiliaries such as steering gear and certain ventilation fans which are so essential that they must be automatically restarted upon restoration of power.

Emergency Run

Many motor starters are equipped with an emergency run feature, particularly controllers for certain vital auxiliaries with stand-by units or for auxiliaries (such as ammunition hoists) where stopping in the middle of an operating cycle is a potential source of danger. By the use of this feature an operator renders the overload-relay trip inoperative so that the auxiliary can be operated with the motor running in an overloaded condition until the stand-by unit can take over, or until the operating cycle is completed, or until the existing danger is averted.

There are several ways of providing the emergency run feature for motor starters. With manual starters, emergency run is usually obtained by holding down a rod or lever that prevents the overload relay from tripping open the main contacts, or by holding closed a "Start–Emergency Run" button or lever that holds the main contacts closed irrespective of the tripping action of the overload relay mechanism. With magnetic starters the emergency-run feature is obtained by shunting the overload-relay contacts with a momentary-contact push button or switch. In this way the circuit to the operating coil of a main contactor may be closed or maintained closed when the motor is overloaded and the overload relay contacts are open. One method of providing the emergency feature for a magnetic starter is illustrated in the diagram of figure 95.

One of the most common methods of providing the emergency run feature on magnetic starters with low-voltage protection is to arrange the control circuit so that the "Start" button also serves



Courtesy of Ward Leonard Elect. Co., Mt. Vernon, N. Y.

Figure 97.—Across-the-line starter with low-voltage release and pilot-switch control.

SYMBOLS

L1—L2—L3—Line	OL—Overload Relay
LC—Line Contactor	M—Motor
T1—T2—T3—To Motor	PS—Pressure Switch

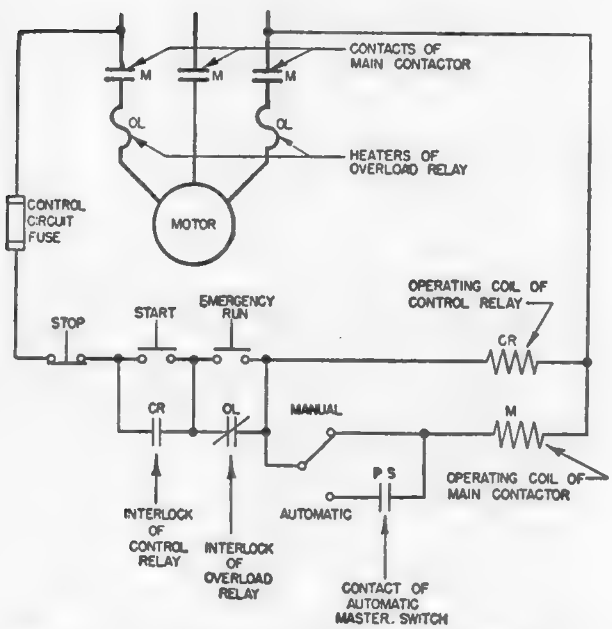


Figure 98.—Across-the-line starter with low-voltage release, pilot-switch and hand control.

as an "Emergency Run" button. This method is illustrated in the control diagram of figure 96. If it is desired that the motor be run even though an overload condition persists, the momentary-contact button is held in the closed position so that the *OL* contact is ineffective in opening the circuit to the *M* coil.

Pilot-Switch Control

Certain motor-driven auxiliaries are automatically started and stopped by a pilot switch that is actuated by pressure, liquid level, temperature, or mechanical linkage with other equipment. Examples of these auxiliaries are pumps that are controlled by float switches, air compressors controlled by pressure switches, and refrigerator compressors controlled by low-pressure switches. In practically all types of pilot-switch control the pilot-switch contacts are set to open and close within certain prescribed limits of the governing condition whether it be pressure, liquid level, temperature, or mechanical travel. A pressure switch, for example, might be set to start a compressor when the air pressure in a storage tank goes below 100 pounds and to stop the compressor when the pressure reaches 150 pounds.

The simplest form of a pilot-switch control is illustrated in figure 97. A maintaining-contact-type push button is included in the control circuit to complete the circuit up to the point of the pilot switch. Once the "Start" button is operated, the motor operation is dependent upon the action of the pilot switch. This type control provides overload protection and low-voltage release when the motor is in operation.

It is desirable with larger motor applications using pilot-switch control to have a means of starting the motor for test purposes when the pilot-switch contacts happen to be open. This can be done with a low-voltage release circuit by connecting, as shown in figure 98.

The normally closed "Stop" button and the normally open "Start" and "Emergency" buttons are the spring return type. The "Man-Auto" Switch is of the maintaining-contact type. With the "Man-Auto" Switch in the automatic position where it closes a set of contacts in series with the pilot switch *PS*, operation of the control is as follows:

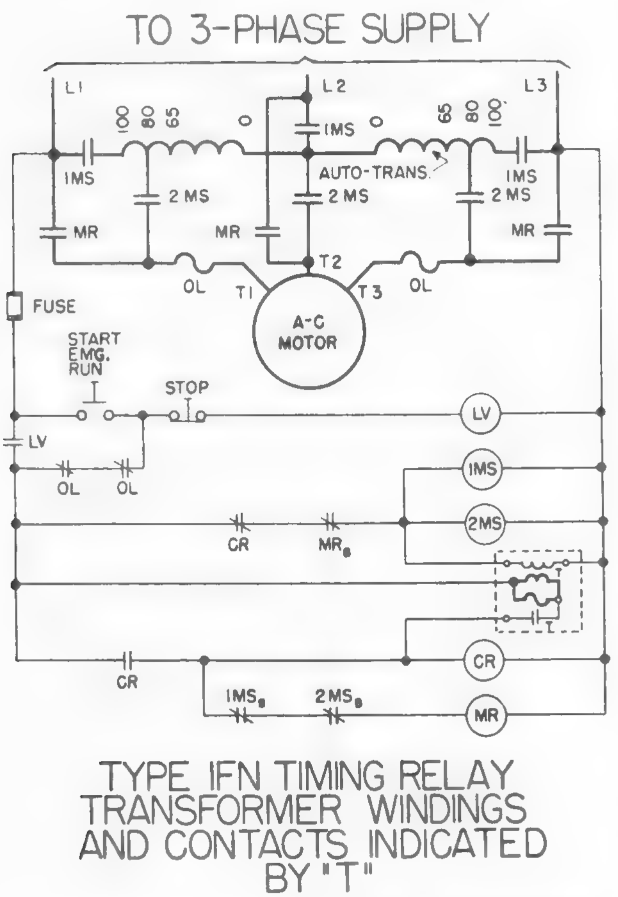
The *CR* relay is energized by pressing the "Start" button. This closes and *CR* contact in series with overload relay contact *OL* to seal in the *CR* relay coil. The *CR* contact is in series with the pilot switch *PS* and the *M* contactor coil. Contactor *M* is then controlled from the pilot switch until CR operates to open its contact. The *M* contactor connects or disconnects the motor to or from the line as required by the pilot switch.

It will be seen from figure 98 that with the "Man-

Auto" Switch in the position shown, the motor can be controlled manually from the "Start" and "Stop" buttons. The *CR* relay in conjunction with the momentary contact push buttons provides the feature of low-voltage protection.

Reduce-voltage starters are applied on certain large motors to limit the amount of inrush current at starting. They are not generally used with motors less than 25 horsepower in rating, but this depends in some degree on the generating capacity of the ship and the effect of heavy starting currents on the electric plant as a whole. Starting inrush currents persist for only a fraction of a second; but if they are of sufficient magnitude, they can trip circuit breakers or result in serious voltage drops on the entire electrical distribution system.

The most common type of reduced-voltage starter found aboard ship make use of an auto-transformer. The primary winding of the transformer is connected to the line, and the motor is connected to secondary taps during the starting period. The control is arranged to remove the transformer automatically from the line after a predetermined time. This permits the motor to reach a speed where its counter generated voltage is of sufficient magnitude to keep the current within desirable limits with full line voltage applied. The automatic change from reduced voltage to full-line voltage is accomplished by a timing relay operating in conjunction with two sets of contactors, as shown in figure 99.



Courtesy of Westinghouse Electrical Corp.

Figure 99.—Reduced-voltage starter with low-voltage protection.

The timing relay shown in the diagram is a thermal type which closes a set of bimetal contacts in a predetermined time after being energized. A description of this type of relay is given in a later discussion on control devices.

The operation of the control begins with the closing of the "Start-Emergency Run" button which completes the circuit to the *LV* relay coil. Relay *LV* picks up and closes contact *LV* completing a circuit to coils 1*MS* and 2*MS* and the primary transformer winding of the timing relay. Contactors 1*MS* and 2*MS* close to apply reduced voltage from the auto-transformer to the motor. After a predetermined time interval, relay *T* closes its contact to energize the CR relay coil. Operation of this relay opens its normally closed CR contact in series with coils 1*MS* and 2*MS* and the timing relay primary transformer winding. A normally open *CR* contact closes to seal in the *CR* coil. The opening of the 1*MS* and 2*MS* main contacts will disconnect the auto-transformer from the circuit. The closing of the normally closed contacts $1MS_B$ and $2MS_B$ completes a circuit to the coil of contactor *MR* through a *CR* contact. The closing of the *MR* contacts in the power circuit applies full voltage to the motor.

Contactors 2*MS* and *MR* are usually mechanically interlocked. The power to the motor will be momentarily interrupted during the transition period or switching from the starting to the running conditions.

After the motor has been started it will continue to run unless the *UV* relay coil is de-energized by operation of the overload relay, a low-voltage condition, loss of power, or operation of the "Stop" push button.

Reversing Across-the-line Starter

Certain equipment such as ammunition hoists,

capstans, boat hoists, and airplane cranes, require motors that can be reversed. A three-phase a-c motor can be reversed by interchanging two of the three power leads to the motor. A typical method of doing this with magnetic control is shown in figure 100.

Lines L_1 and L_3 are interchanged by action of the two contactors *F* and *R*. When the "Forward" push button is pressed, a circuit is completed to the *FC* coil. The *FC* contactor picks up and connects the motor directly to the line. The auxiliary contact *FC* maintains the circuit when the "Forward" button is returned by spring action to its normal position. Similarly, a circuit is completed to the *RC* contactor when the "Reverse" button is operated. The purpose of the normally closed contacts is to prevent an operator from simultaneously energizing the *F* and *R* contactors, which action would short circuit the power supply, as can be seen from the power circuit of figure 100.

Two-Speed Starters

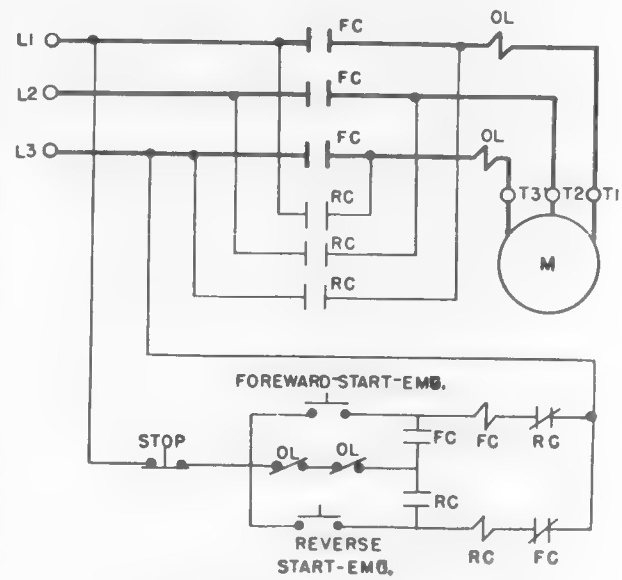
Alternating-current motors are fundamentally single-speed machines, since the speed is governed by the frequency of the power supply and the number of poles in the stator. There are, however, a number of applications which require two-speed motors; for example, ventilation fans, capstans, boat cranes, and ammunition hoists.

Two general methods are used for changing the speed of a-c motors, both of which provide a means of changing the number of poles in the stator. One method is to have two separate stator windings in the stator slots with each winding designed to provide the number of poles required for a definite speed. This type of motor may be considered as two motors in one casing, with one set of windings idle while the other is in use.

The other method is to provide a single-winding motor with two separate winding connections for operation at full speed and half speed, respectively. The connections supplied by a manufacturer will depend on which of the following characteristics are required at both high and low speeds: constant torque, variable torque or constant horsepower. These connections are mentioned in chapter 8.

A typical two-speed starter for a two-winding motor is illustrated in the elementary diagram of figure 101.

The control is arranged to connect either the high-speed winding or the low-speed winding to the

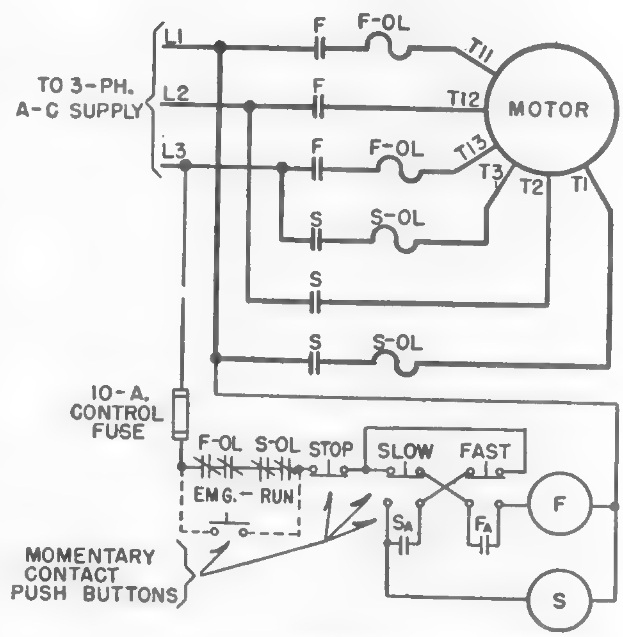


Courtesy of Ward Leonard Elect. Co., Mt. Vernon, N. Y.

Figure 100.—Reversing across-the-line starter.

SYMBOLS

L1—L2—L3—Line	FC—Forward Contractor
T1—T2—T3—To Motor	RC—Reverse Contractor
M—Motor	OL—Overload Relay



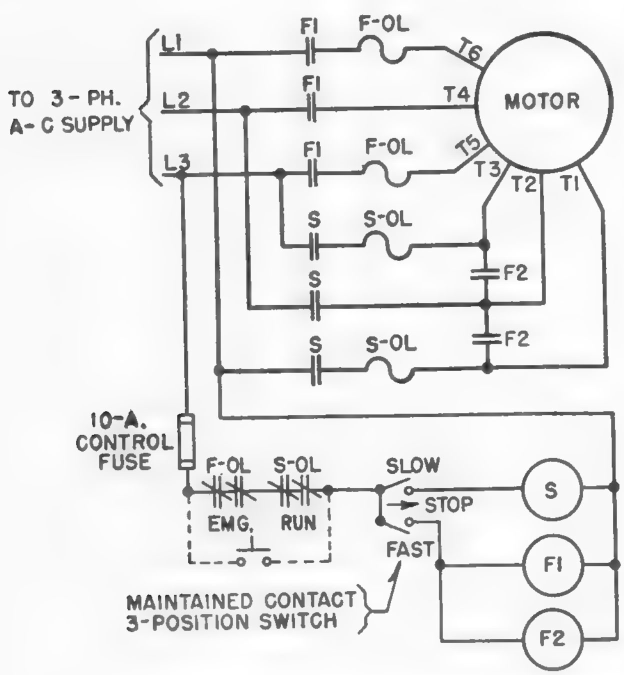
Courtesy of Westinghouse Electrical Corp.

Figure 101.—Two-speed across-the-line starter for two-winding motor.

line as desired by the operator. Two sets of overload relays are used, as the current requirements for the two speeds are different.

When the "Fast" push button is pressed, it closes one set of contacts to energize the high-speed contactor *F*. An auxiliary contact of *FA* closes to maintain the circuit to the *F* coil, preventing the contactor from dropping out after the "Fast" push button has been released. The closing of the *F* contacts in the power circuit connects the high-speed winding of the motor to the line. Similarly, the low-speed winding of the motor is connected to the line by pressing the Slow push button. Protection against energizing both windings at the same time is provided by the contactors *F* and *S* mechanical interlocks.

With a single-winding motor the control is similar except that the number of power contacts for the "Fast" connection are increased to accomplish the change from a parallel connection of stator winding to a series connection. The arrangement of contacts and their relation to the motor winding is illustrated in the elementary wiring diagram of figure 102.



Courtesy of Westinghouse Electrical Corp.

Figure 102.—Elementary diagram of two-speed across-the-line starter for single-winding motor.

With the *S* contactor closed, motor leads T_1, T_2, and T_3 are connected directly to the line, and the stator windings are connected in series to provide the maximum number of poles. With contactors *F*1 and *F*2 closed and *S* open, T_1, T_2, and T_3 are connected together, and T_4, T_5, and T_6 are connected directly to the line. This provides a parallel connection of stator windings, with the number of poles reduced to half the number of the series connection.

TWO-SPEED REVERSING REDUCED-VOLTAGE STARTER

A two-speed reversing reduced-voltage starter combines the elements of all the control circuits discussed thus far.

The elementary diagram of figure 103 is representative of the more complicated a-c control circuits that an engineering officer might be called upon to analyze in locating trouble or in the training of enlisted personnel.

Six sets of contactors are used in the power circuit to accomplish the required changes in connections of the motor to the power supply. The two three-pole contactors designated as *H* and *L* serve to reverse the motor or in a lifting application provide hoisting and lowering. This is a matter of simply interchanging two of the motor supply lines as previously discussed. When the five-pole "Starting" contactor, designated as *S*, is closed, the auto-transformer is inserted in the power circuit to provide reduced voltage starting. The three-pole "Run" contactor, designated as *R* bypasses the auto-transformer when closed and applies full-supply voltage to the motor. Speed change is accomplished by the two three-pole contactors *HS* and *LS* connected to the high-speed and low-speed windings of the motor, respectively.

The control is operated from two push button stations, a momentary-contact type for selecting "Hoist" or "Lower" and a maintaining-contact type for selecting high speed or low speed. When the "Hoist" button is pressed, it closes a circuit through a normally closed *L* contact to the *H* contactor coil, which closes its respective contacts in the power circuit. An auxiliary contact of *H* closes to maintain the circuit to the *H* coil. Similarly, the *L* coil is energized when the "Lower" button is pressed. Normally closed contacts of *H* and *L* are inserted in the *L* and *H* coil circuits, respectively, to prevent closure of the contactors at the same time. The

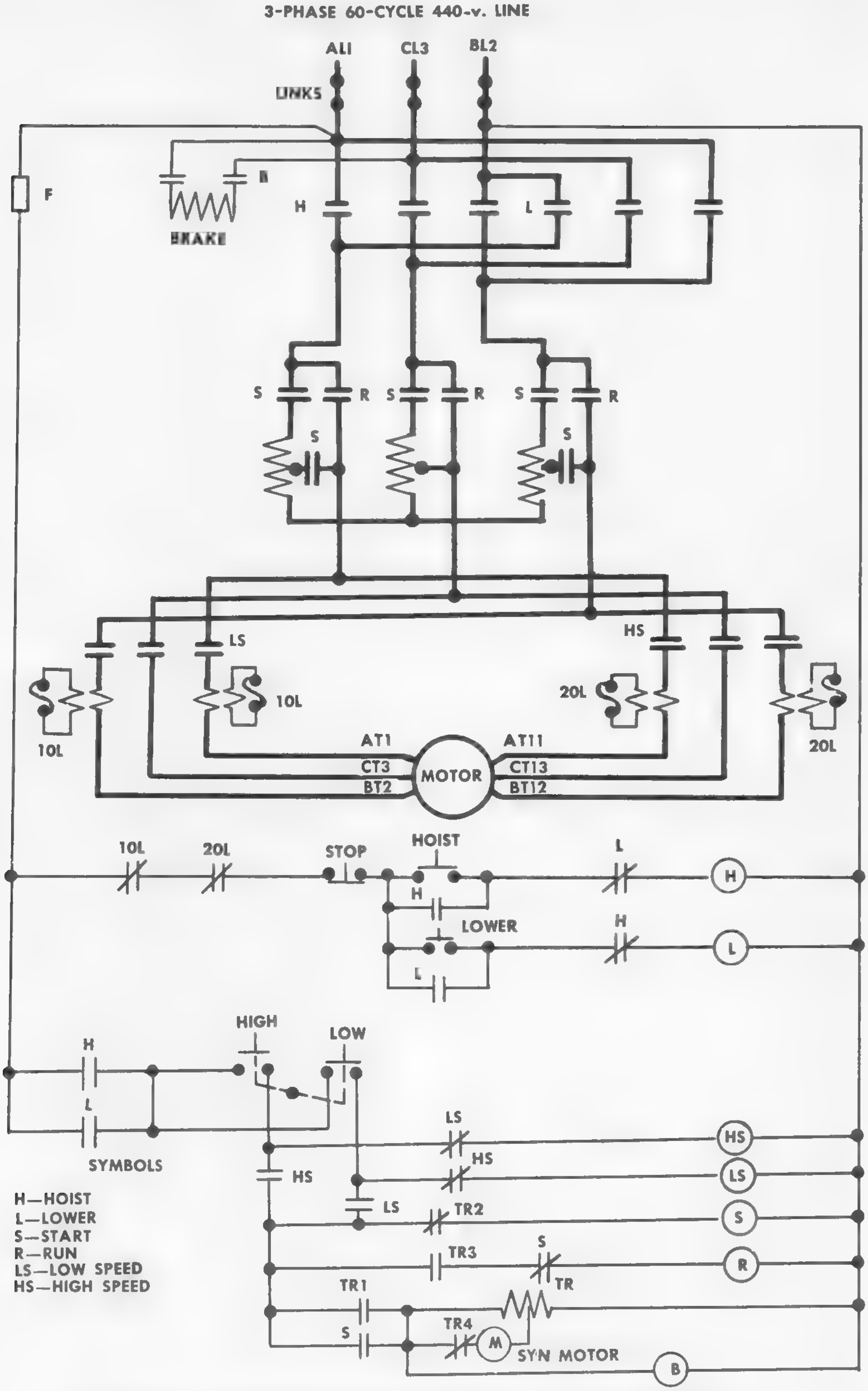


Figure 103.—Two-speed reversing reduced-voltage starter for two-winding motor.

transfer from "Hoist" to "Lower", or vice versa, must be initiated by pressing the "Stop" button and de-energizing whichever contactor is closed. This is in effect stopping the motor before connecting it to run in the opposite direction.

The push-button station for speed selection is either in the "Low" position or "High" position at all times, so that when either H or L closes, a circuit is made to the HS or LS coil through the auxiliary contacts of H or L. The LS and HS normally closed auxiliary contacts prevent the possibility of HS and LS closing at the same time. The main contacts of HS and LS in the power circuit direct the power supply to the high-speed or low-speed motor windings.

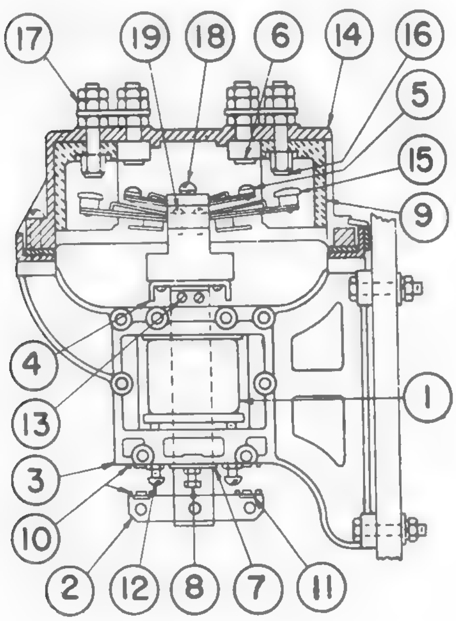
The operation of the timing relay with the "starting" and "running" contactors S and R is identical to that described under reduced-voltage starting. As previously described, the motor will remain connected through the auto-transformer and will operate at reduced voltage until the timing relay operates to open the circuit to the S coil and close the circuit to the R coil, thereby putting the motor directly across the line.

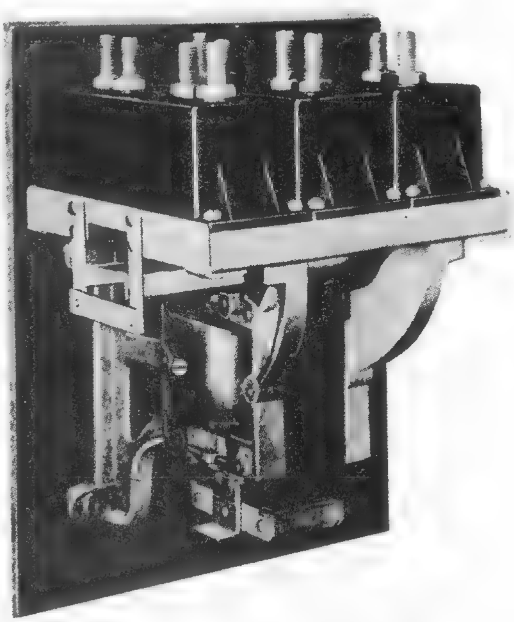
Panel-Wiring Diagrams

The only difference between the elementary diagrams thus far discussed and panel-wiring diagrams is that the latter shows the wiring with respect to the actual location of the apparatus on the panel and details for connection of external equipment to the panel.

Manufacturers generally label all connections with letters and numbers to simplify the electrician's job of connecting external apparatus and checking defective circuits. This labeling is usually marked on control devices, so that it becomes a relatively easy task to check the actual panel with the panel-wiring diagram and its corresponding elementary wiring diagram.

The student engineering officer will find that the ability to develop elementary diagrams from panel diagrams is of great value in the understanding of control circuit operation. Also, there are occasions

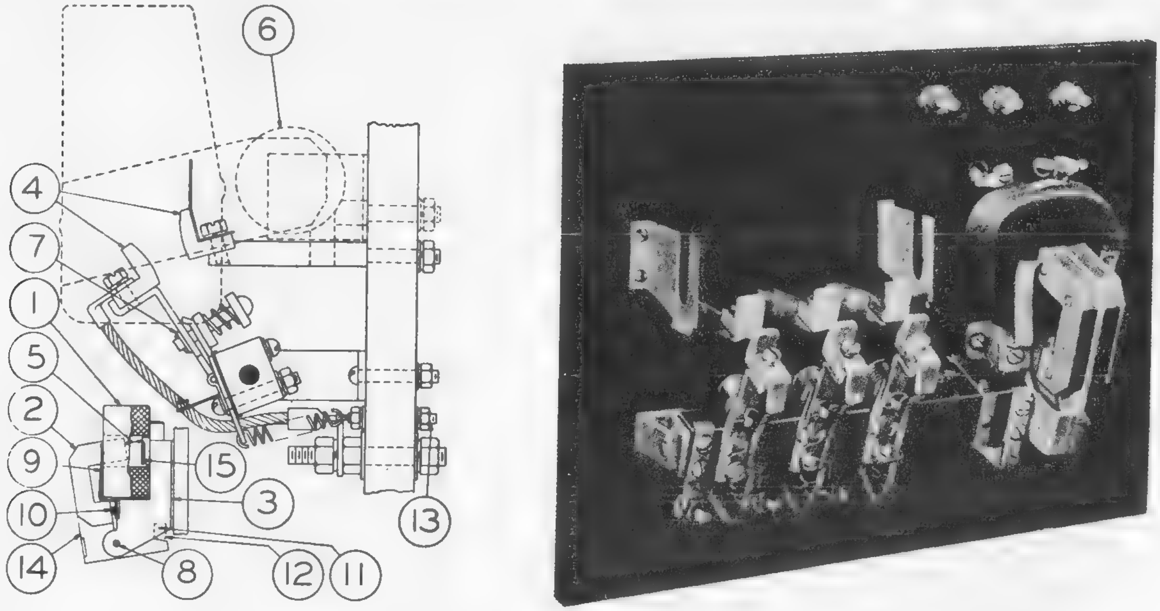




1. Coil
2. Plunger
3. Magnet Frame
4. Carriage
5. Main Movable Contacts
6. Main Stationary Contacts
7. Plunger Guides
8. Guide Screws
9. Arc Shield
10. Ground Surfaces
11. Lag Loop
12. Coil Holding Screws
13. Carriage Bolts
14. Hood
15. Movable Arcing Contacts
16. Stationary Arcing Contacts
17. Terminal Nuts
18. Saddle Holding Screws
19. Arcing Contact Screws

Courtesy of Ward Leonard Elect. Co., Mt. Vernon, N. Y.

Figure 104.—Drawing and photograph of vertical-lift shunt contactor.



1. Coil
2. Movable Armature
3. Magnet Frame
4. Main Contacts
5. Ground Surfaces
6. Arc Shield
7. Spacer Washer
8. Hinge Pin
9. Holding Clamps
10. Screw
11. Cotter Pin
12. Bakelite Stop
13. Spring Adjustment Stud
14. Armature Bracket
15. Lag Loop

Courtesy of Ward Leonard Elect. Co., Mt. Vernon, N. Y.

Figure 105.—Drawing and photograph of clapper-type shunt contactor.

where only the panel diagram is furnished, and it becomes necessary to construct an elementary diagram to facilitate the location of trouble.

A-C Control Devices

Contactors.—The contactors used for connecting motors to the power supply are manufactured in a wide variety of sizes and ratings ranging from 25 amperes to 600 amperes for normal below-deck auxiliaries. Contactors vary in construction and design depending on the service for which they are intended and their ability to withstand shock.

Discussion of contactors in this chapter is limited to two general types known as the vertical-lift type and the clapper type. Descriptions of other types which the Navy employs is not considered necessary for the instruction purposes of this text. It should be noted, however, that shockproofing is a primary consideration in the design of Navy contactors. Contactors are classed in accordance with their ability to withstand certain degrees of shock without damage and their ability to remain closed or open under shock of a certain intensity.

Figure 104 shows the component parts and the operating principle of a vertical-lift contactor.

The vertical-lift contactor, generally used with small motor applications, is furnished with two or more contacts in series per pole. The contactor is designed to permit a suitable air gap for quickly extinguishing arcs in the lower horse power range when the contactor opens.

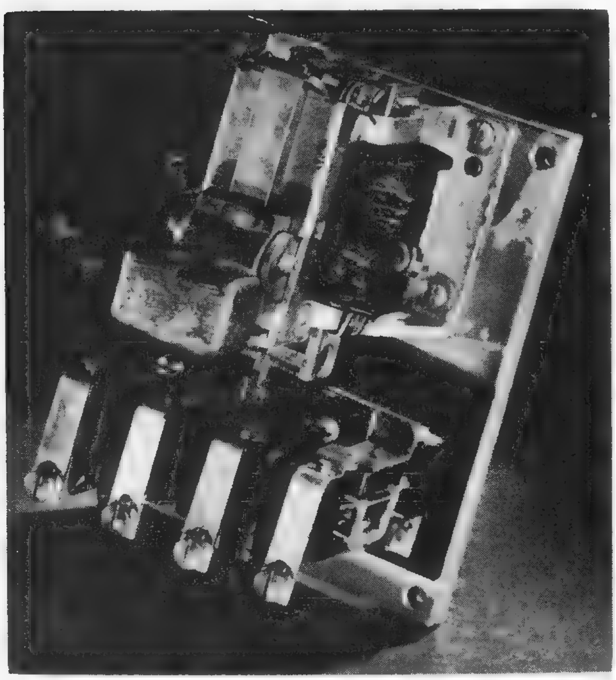
Figure 105 shows the component parts and the operation principle of a clapper-type contactor.

Clapper-type contactors are generally used with the larger horse power motors which require a special means to extinguish the arc when the contactor opens.

One of the basic differences between a-c and d-c contactors is that shading coils must be used with a-c contactors. It has been shown that the value of the exciting current reaches zero twice every cycle. The result is that the magnet starts to open every time the current reaches zero. This condition is eliminated by the use of a shading coil of short-circuited winding placed around part of the pole face. The current induced in this shading

coil produces a flux in that part of the magnetic circuit surrounded by the shading coil; this flux is out of phase with the main flux. The combination of these two fluxes produces a pull which never reaches zero.

Maintenance of contactors.—The chief point to check in the inspection of contactors is the condition of the contact tips. Some contactors are supplied with silver tips which require little attention until the tip-wear allowance is gone. Tips of this type should be replaced when the allowable wear has been reached. They should not be filed or dressed, as this only results in loss of material. Contacts that do not have silver tips can be dressed up with a fine file when the contact surfaces are pitted or show small metal beads. These contacts are usually of sufficiently rugged construction to withstand a limited amount of filing before replacement. Sandpaper or emery cloth should never be used on contacts, as sand and other such abrasives imbed themselves in the metal. Contacts normally wear to give the best contact surface, and it is only in cases where excessive arcing occurs under overload conditions that dressing becomes necessary.



Courtesy of Westinghouse Electrical Corp.

Figure 106.—Voltage relay.

The use of a lubricant on contacts and bearings of contactors is to be avoided, since oil quickly collects dust; and unless parts are frequently cleaned, the dust will interfere with the operation. Furthermore, oil surfaces that collect dust may also result in an arc between live parts of the contactor. When it does become necessary to apply a lubricant to bearings, only a light machine oil should be used.

Low spring pressure and consequent low contact pressure should be guarded against to avoid excessive heating of contacts. Excessive heating increases the resistance, and the increased resistance may cause sufficient arcing to weld the contacts together. New springs should be installed where there is evidence that the contact pressure is below normal.

The contact gap should be maintained in accordance with manufacturers' instruction. The gap is measured at the heel of the contactor in the full open position.

Arc shields should always be down in the normal operating position. Arc shields should be renewed before the moulded material is burned away sufficiently to expose the metal parts to the arc.

In the more complex starters, operation troubles frequently arise because the auxiliary contacts fail to perform their function. Auxiliary contacts, if there be any, should be checked to insure that they have the correct travel and correct pressure, that the contact surfaces are clean, and that all connections to the auxiliary contacts are clean and tight.

Alternating-current contactors may develop excessive humming owing to misalignment of magnet core and moving armature, low operating voltage, broken shading coil, or excessive spring pressure. Sealing surfaces of the magnet should be checked, and any corrosion should be removed. Any distortion of the moving armature should be corrected. Defective shading coils should be replaced and excessive spring tension reduced.

The amount of maintenance required on contactors depends largely on the frequency of operation. On certain hoisting equipment the duty is severe and the equipment requires frequent inspections and replacements. With auxiliaries operating at the same speed over long periods of time, however, contactors require little maintenance. In general, every ship will be found to carry a liberal set of contactor spares regulated to suit the duty requirements of the application.

Relays.—The relays generally used with a-c motor starters include (1) voltage relays of the normally open or normally closed type, (2) thermal overload relays, and (3) timing relays.

Voltage relays are ordinarily used in starter circuits in connection with pilot switches for undervoltage protection. They are sometimes used to associate two circuits in such a way that one will not operate unless certain conditions are fulfilled by the other. Voltage relays are very similar to small contactors in appearance and operation and require about the same maintenance and repair. Figure 106 shows a typical voltage relay.

Thermal overload relays are of two types, the compensated type and the noncompensated type. In many installations protection against overload is required whether the motor or controller be situated in a cold or hot space. This requires an overload relay which is compensated for changes in ambient temperature. One of the methods used to accomplish this function is illustrated in figure 107.

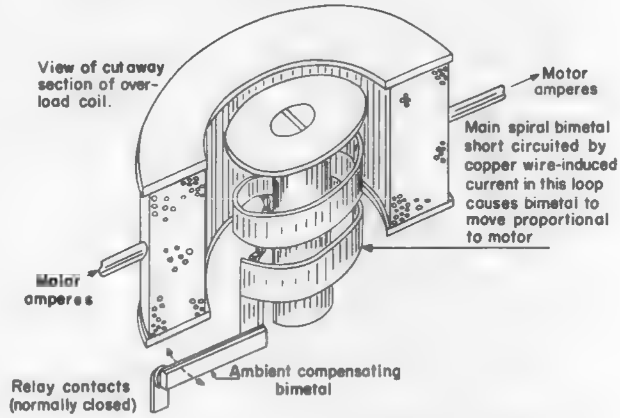
This relay operates on an induction principle, the motor current being fed through a series coil which acts as the primary of a transformer and a spiral bimetal strip which acts as the secondary. The spiral bimetal is short circuited by a copper wire so that the current flow is proportional to the current in the primary coil. The lower end of the spiral bimetal rotates and opens a set of contacts when it has deflected a given amount. The compensating device consists of a bimetal strip which deflects in the opposite direction to the spiral bimetal; this corrects for the effect of different ambient temperatures.

One type of noncompensated type relay consists principally of a bimetal strip which is so calibrated that it will bend sufficiently to permit a latch to trip and open the contacts if the motor is overloaded. This action is illustrated in figure 108.

Timing relays are used principally with reduced-voltage starters on shipboard applications and are of the thermal, mercury, or bellows type. They permit a definite time interval between the starting of a motor at reduced voltage and the application of full-line voltage.

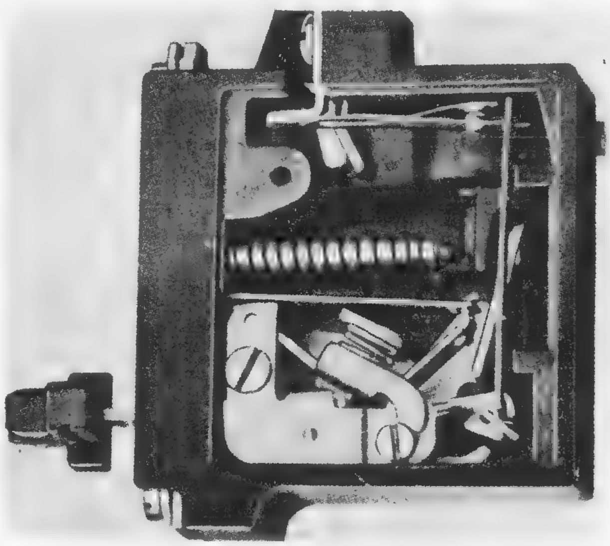
The operation of a typical type of thermal relay used in conjunction with reduced-voltage starters may be readily understood from the diagram of figure 109.

When an a-c voltage that is within the operating limits is applied to terminals of the transformer primary winding, a low voltage will be induced into the secondary transformer winding and a relatively large current will circulate in the secondary circuit. This current flows through the active moving bimetal and contact assembly strip. As the bimetallic strip has a relatively high resistance compared to the resistance of the transformer secondary winding, considerable heat will be generated in this part. Because of this heat, the lower bimetallic strip will deflect in an upward direction and fully close the relay contacts. Changes in ambient



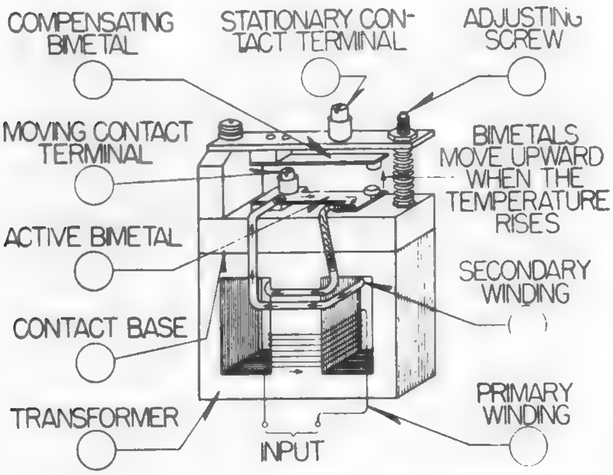
Courtesy of General Electric Co.

Figure 107.—Compensated overload relay.



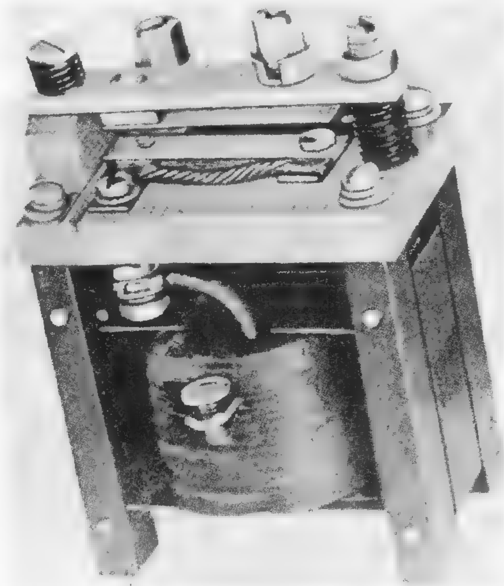
Courtesy of General Electric Co.

Figure 108.—Noncompensated overload relay.



Courtesy of Westinghouse Electrical Corp.

Figure 109.—Electrical and mechanical diagram of thermal-type timing relay.



Courtesy of Westinghouse Electrical Corp.

Figure 110.—Thermal-type timing relay.

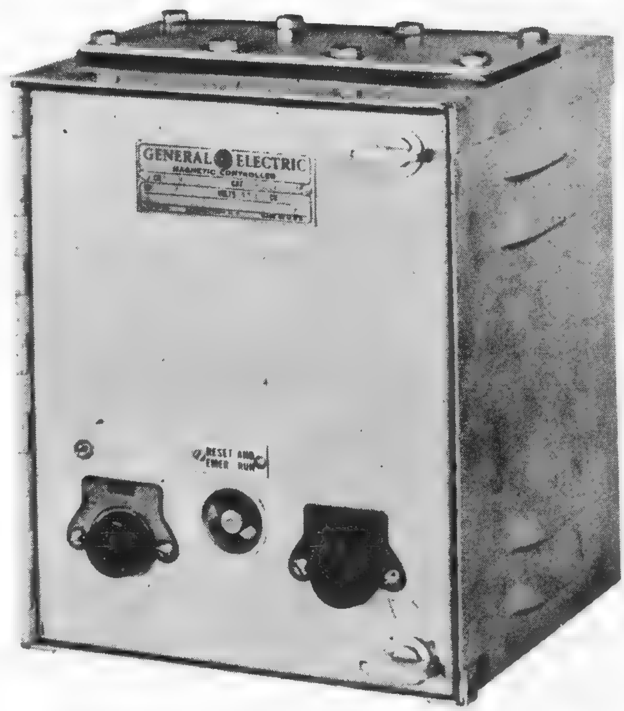
temperature will deflect upper and lower bimetallic strips an equal amount in the same directions so that the gap between upper and lower contacts with the relay de-energized is maintained constant for all ambient temperatures.

The physical appearance of a typical thermal-type timing relay is given in figure 110.

General Construction of A-C Motor Starters

Motor starters for ships of the Navy are constructed in exact accordance with Bureau of Ships specification requirements. Rugged construction and the ability to withstand shock are principal features of Navy starters, particularly in the case of combat ships, which are subject to the shock of their own gun batteries and near misses or hits by the enemy. The development of contactors and relays that can maintain their operating positions while being subjected to extreme shock has made possible the application of electric motors on auxiliary equipment formerly driven by other means.

Motor starters are furnished with enclosures to suit their location aboard ship. The control devices are generally mounted on shock resistant insulation panels inside the enclosure. Below-deck starters are generally furnished with drip-proof enclosures similar to that shown in figure 111. Spray-tight enclosures are used below deck in locations that may be exposed to unusually damp conditions. In certain locations below deck which are subject to



Courtesy of General Electric Co.

Figure 111.—Motor starter with drip-proof enclosure.

accumulation of explosive gases or dust, explosion-proof starters are required. These starters are equipped with an enclosing case which is designed and constructed to withstand an explosion of gas or dust occurring within it and to prevent the ignition of the surrounding space owing to arcing of contacts within it. A typical explosion-proof enclosure is shown in the photograph of figure 112.

Where it is required to have starters mounted on weather decks, watertight enclosures are used. These enclosures are designed to withstand the effects of deck wash and weather without leakage, and they are subjected to the Bureau of Ship's leakage tests before acceptance by the Navy. The type of construction used with watertight enclosures is illustrated in figure 113.

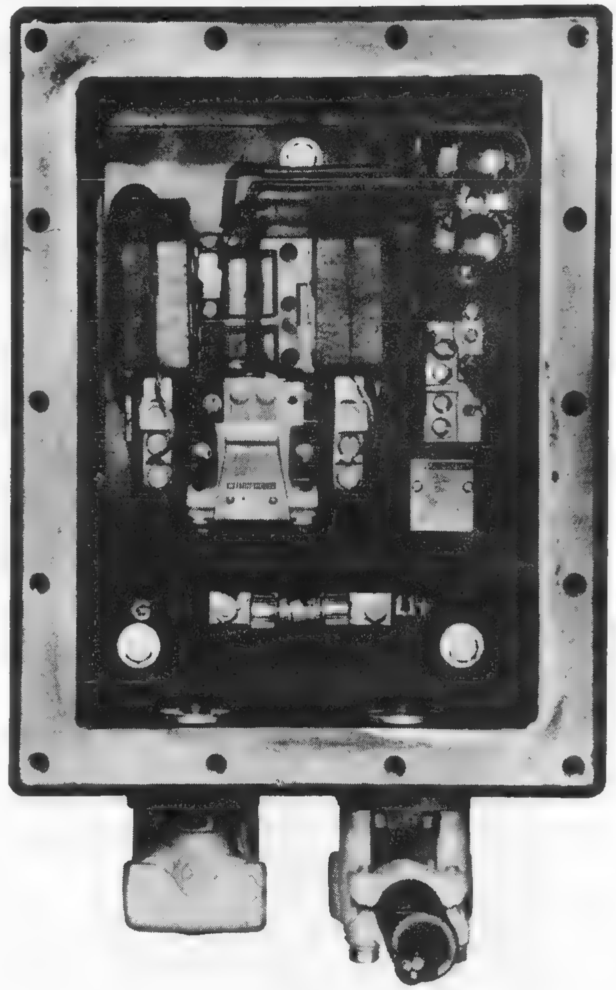
Maintenance of Starters

Most of the maintenance required on starters has been discussed in the section on individual devices. In carrying out inspections, however, it is advisable to check periodically all wiring connections for tightness, insulation on wiring, dryness and cleanliness of individual parts, and enclosure. Operation should be checked by stopping and starting the motor several times.

There is very little maintenance required on manual starters, except to check the tightness of the connections and the condition of overload relays.

Maintenance of magnetic starters is measured by the number of devices to be checked on an individual starter and the frequency of operation. Hoisting cycles come under the classification of heavy duty service, and the starters for these applications require considerably more maintenance than auxiliaries that run at constant speed.

Trouble in simple across-the-line starters can be quickly located with the use of a voltage tester. This voltage tester is first put across the incoming ines to see that there is power available to the starter. It is then used to check the control fuse and the position of the overload relay contacts. This is done by placing one lead from the voltage tester on one side of the control circuit and proceding on the other side of the control circuit with the other lead, placing it successively on the lead side of the fuse and on the overload-relay contacts. This tests the circuit continuity up to these points, and it can be continued through other items of the control circuit up to the terminals of the contactor coil. If tests show that there is power at the coil, then the



Courtesy of Westinghouse Electrical Corp.

Figure 112.—Motor starter with explosion-proof enclosure.

coil is either burnt out, the supply voltage is too low, or the contactor armature is not free to close when the coil is energized.

When the cause of a starter's failure to operate has been determined, the power supply should be disconnected before proceeding with repair or replacement. A defective coil in a contactor or relay is generally replaced from spare parts.

An ohmmeter test will generally locate any defective contact or loose connection that is causing trouble. A further check can be made, however, with the control circuit energized. Under this condition the contacts of a device are mechanically opened and closed, and the effect is noted on other

devices directly controlled by these contacts. In performing this test the motor should be disconnected from the starter, and devices should be mechanically opened and closed with an insulated tool. This technique will be considered in more detail in the next section.

Direct Current Motor Starters

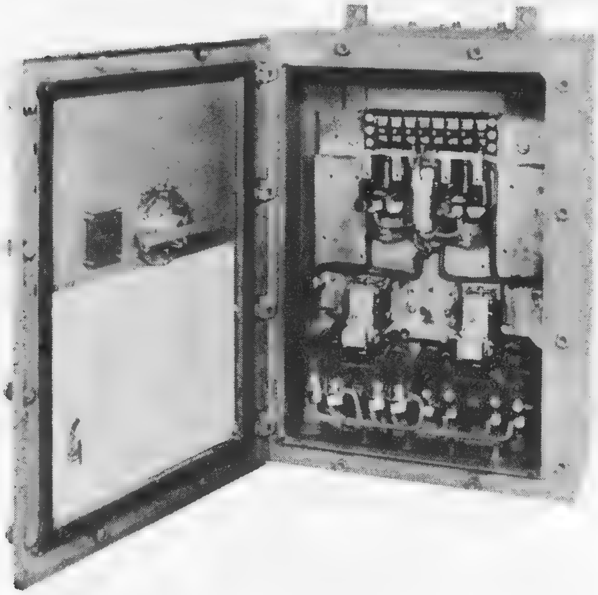
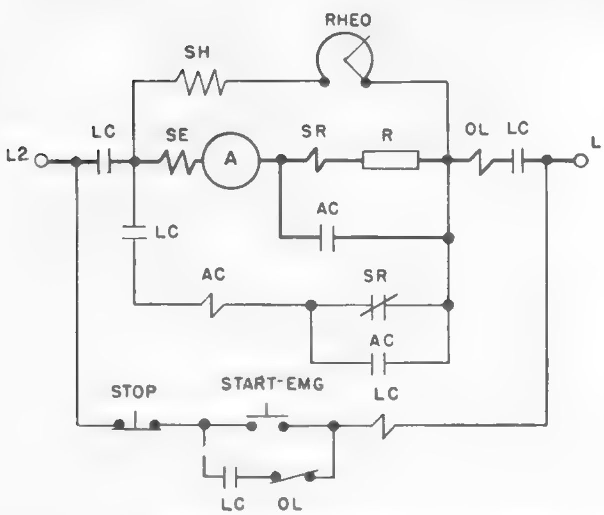


Figure 113.—Motor starter with watertight enclosure.



Courtesy of Ward Leonard Elect. Co., Mt. Vernon, N. Y

Figure 114.—Elementary wiring diagram of d-c starter with low-voltage protection and shunt-field control.

SYMBOLS

L1-L2—Line
SH—Shunt Field
SE—Series Field
A—Armature
LC—Line Contactor
RHEO—Field Rheostat
R—Starting Resistor
AC—Accel. Contactor
SR—Series Relay

While a-c systems are installed on practically all combat ships of the Navy, d-c systems are found on most of the auxiliary ships in the fleet. Adaptable to all applications requiring variable-speed drive, the d-c motor is successfully applied with cargo winches, windlasses, and other hoisting machinery on auxiliary ships. The modern battleship, cruiser, or aircraft carrier generally uses hydraulic speed changers in conjunction with constant-speed a-c motors for steering gear and other applications requiring a wide range of speed change, but on the smaller auxiliary ships this becomes impractical because of weight and size.

The starting of all d-c motors, with the exception of fractional horsepower sizes, requires a temporary insertion of resistance in series with the armature circuit to limit the high inrush current at standstill. Because of this consideration the starting resistance cannot be safely removed from the line until the motor has accelerated in speed and the counter electromotive force is of sufficient strength to limit the current to a safe value.

Auxiliary motors located below deck generally drive constant-speed equipment. A rheostat in the shunt field circuit is, however, provided to furnish speed control for motors operating with ventilation fans, forced draft blowers, and certain pumps where conditions may require operation at more than one speed.

With motors of small rating one block of starting resistance remaining in the line for a few seconds is generally sufficient to limit the starting current. With the larger motors two or more blocks of resistance are connected in the line at starting and are cut out in steps as the motor accelerates to running speed.

Motors applied with cargo winches and other deck auxiliaries are required to operate over a wide range of speed. Since the speed of a d-c motor with constant load varies almost directly with the voltage, blocks of line resistance are used to make speed changes and also to limit the current at starting. These blocks of line resistance are connected in various combinations as manually selected by a master switch operating in conjunction with a

magnetic controller. Thus, the operator directly controls the amount of resistance in the line and the resulting speed of the motor at all times.

Magnetic D-C Starters for Small Below-Deck Auxiliaries

Magnetic d-c starters incorporate control for overload protection, under-voltage release, and low-voltage protection similar to that discussed in the section on a-c starters. With below-deck auxiliaries the starter is operated from a push-button station or pilot switch arranged for low-voltage protection or release as shown in the typical elementary wiring diagrams of figures 114, 115, and 116.

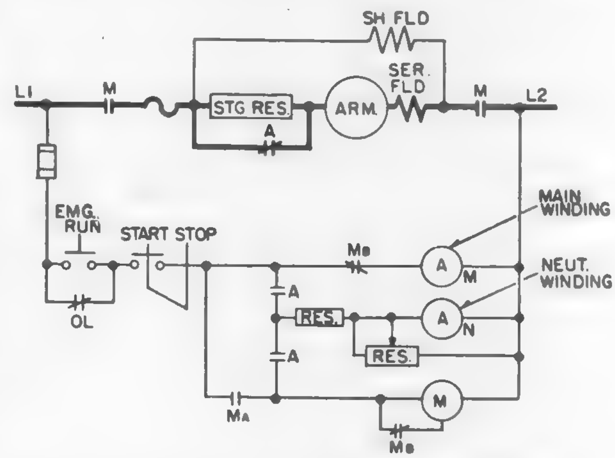
With the line switch closed in the starter circuit shown in figure 114 the coil of contactor *LC* is energized when an operator presses the "Start" button. A normally open *LC* contact in the control circuit closes to bridge the "Start" button contacts and maintain the coil circuit when the button is released. The power supply is connected to the motor through a starting resistor and series relay coil when the contactor *LC* closes. The series relay drops out after the current decreases to 110 percent of full load, closing its contact to pick up the *AC* contactor. This contact shunts out the starting resistance, putting full-line voltage on the motor and permitting it to come up to rated speed. A field rheostat is inserted in the shunt field circuit for the purpose of regulating the field excitation and motor speed.

Operation of the overload relay is similar to that described in the section on a-c starters. Thermal-type relays are generally applied to all below-deck auxiliary starters and are identical in operation to those installed on a-c starters.

The diagram of figure 115 differs from the one shown in figure 114 in that a maintaining-contact push button instead of the momentary-contact type is used to provide the low-voltage release feature. This feature permits the motor to restart automatically with restoration of normal power supply after a condition of power failure or excessive line-voltage drop.

The other elements of the control circuit perform the same functions as figure 114 but employ different means.

Operating the "Start" button energizes the main winding *AM* of the timetactor *A* which closes, removing the short around the starting resistor and closing two auxiliary contacts to energize the neutralizing coil *AN* and the line contactor *M* which starts the motor with the resistance in series. The auxiliary contacts of contactor *M* maintain its circuit through the "Stop" button and overload relay, another auxiliary contact M_B opens to de-energize the timetactor. The timetactor windings are on a copper tube which causes the flux of the timetactor magnetic circuit to decay slowly, so there is a time delay before the armature of the timetactor opens to short out the resistance placing the motor across the line. The neutralizer winding with its variable



Courtesy of Westinghouse Electrical Corp.

Figure 115.—Elementary wiring diagram of d-c starter with low-voltage release.

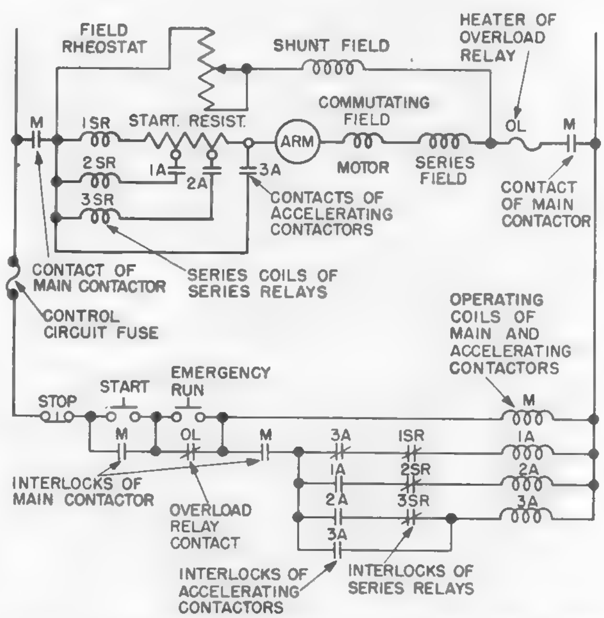


Figure 116.—Elementary diagram of d-c three-step starter

resistor buck the timetactor flux and control the duration of time delay. An auxiliary contact *A* of the timetactor also opens the neutralizer circuit.

THREE-STEP STARTERS FOR LARGE BELOW-DECK AUXILIARIES

When large motors are used with below-deck auxiliaries, more than one step of starting resistance is required. The motor starts with all blocks of starting resistance in the line; as it comes up to speed, these blocks of resistance are removed in steps so that the combination of resistance and counter electromotive force of the motor is always of sufficient value to keep the line current within safe operating limits.

Accelerating relays or timetactors are used in multiple on larger d-c motors to limit the armature current to a safe value by shorting blocks of starting resistance in two or three accelerating steps as in figure 116. Motors of 150-ampere rating and above are generally controlled by manually operated cams.

Automatic pressure, temperature and float switches along with door switches, limit switches, brake circuits and motor-operated accelerating drums may be found as features of shipboard d-c controllers.

Oil dash pots are employed on many applications to control the time delay feature of relays or contactors.

In general most main contactors employ blow-out coils that cause the arc to move up, stretching it and forcing it against the cold arc chutes until the resistance of the path is so high that the voltage is unable to maintain the arc. The core of the blow-out coil with sideplates attached, establishes a magnetic circuit through the arc stream, and the action of the resulting magnetic field is to stretch the arc in the manner described above.

D-C Control for Deck Machinery

General.—Before the extensive use of electric motors aboard ship for powering various deck machinery, steam reciprocating engines were used exclusively. The double-acting steam engine was particularly adaptable on hoisting machinery, since an operator could always maintain complete control of the load in both the hoisting and lowering direction with a minimum use of mechanical braking.

Steam engines, however, are notably inefficient when applied to deck machinery, and on modern ships they have been replaced by electric motors. The control for these applications has been designed to simulate the operating characteristics of steam equipment and provide full protection to the electric motor. It has been designed to operate from a single-drum motor switch that controls the entire hoisting, lowering and necessary braking, by the simple manipulation of a handle to designated positions.

Cargo-winch control is an excellent example of the application of d-c control to deck machinery. The control and motor for a cargo winch must provide a variety of operating features to furnish efficient and safe hoisting and lowering of heavy loads. These essential characteristics are enumerated as follows:

Hoisting:

1. A slow, creeping speed for adjustment of slings or for jogging of loads.
2. A slow speed designed for hoisting a heavy load.
3. Three higher speeds on subsequent points with time-delay features to provide smooth acceleration in the event the master switch is advanced too fast.

Lowering:

1. Power in the lowering direction for unreeling light line.
2. Dynamic braking for use in lowering a load.
3. Step-back provision on fifth point to prevent load from overhauling motor at too high a speed.

Braking:

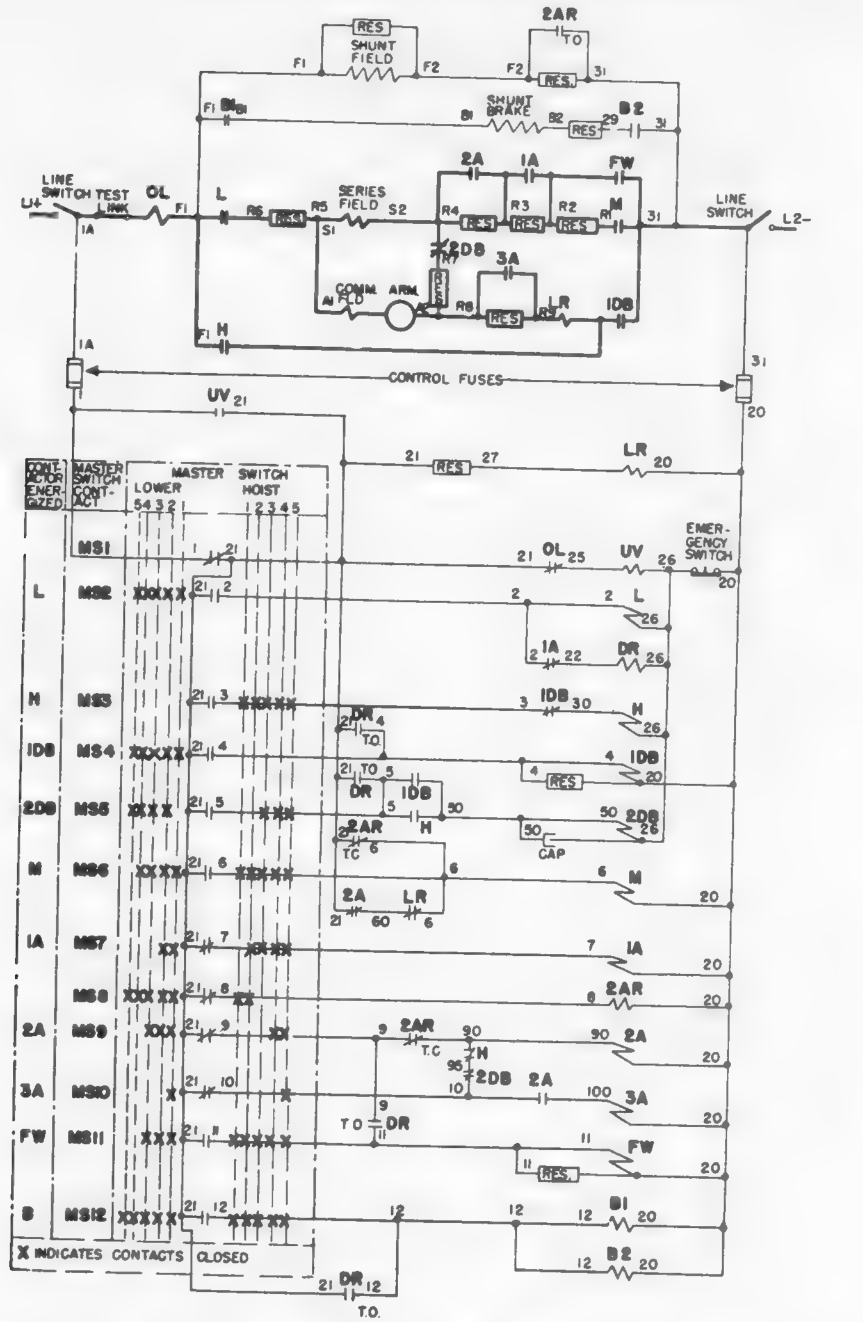
1. Dynamic braking to slow down a load in lowering.
2. A holding brake which sets to hold the load when the master switch is placed in the "Off" position.

Protection:

1. Under-voltage protection.
2. Overload protection.
3. Load protective relay to prevent overhauling loads from overspeeding the motor.

Cargo-winch control is representative of the more complex control circuits found aboard ship. The type of control devices used and the sequence of their operation is very much the same for the equipment of different manufacturers.

Cargo-winch control equipment is subjected to the heaviest duty of any control equipment found

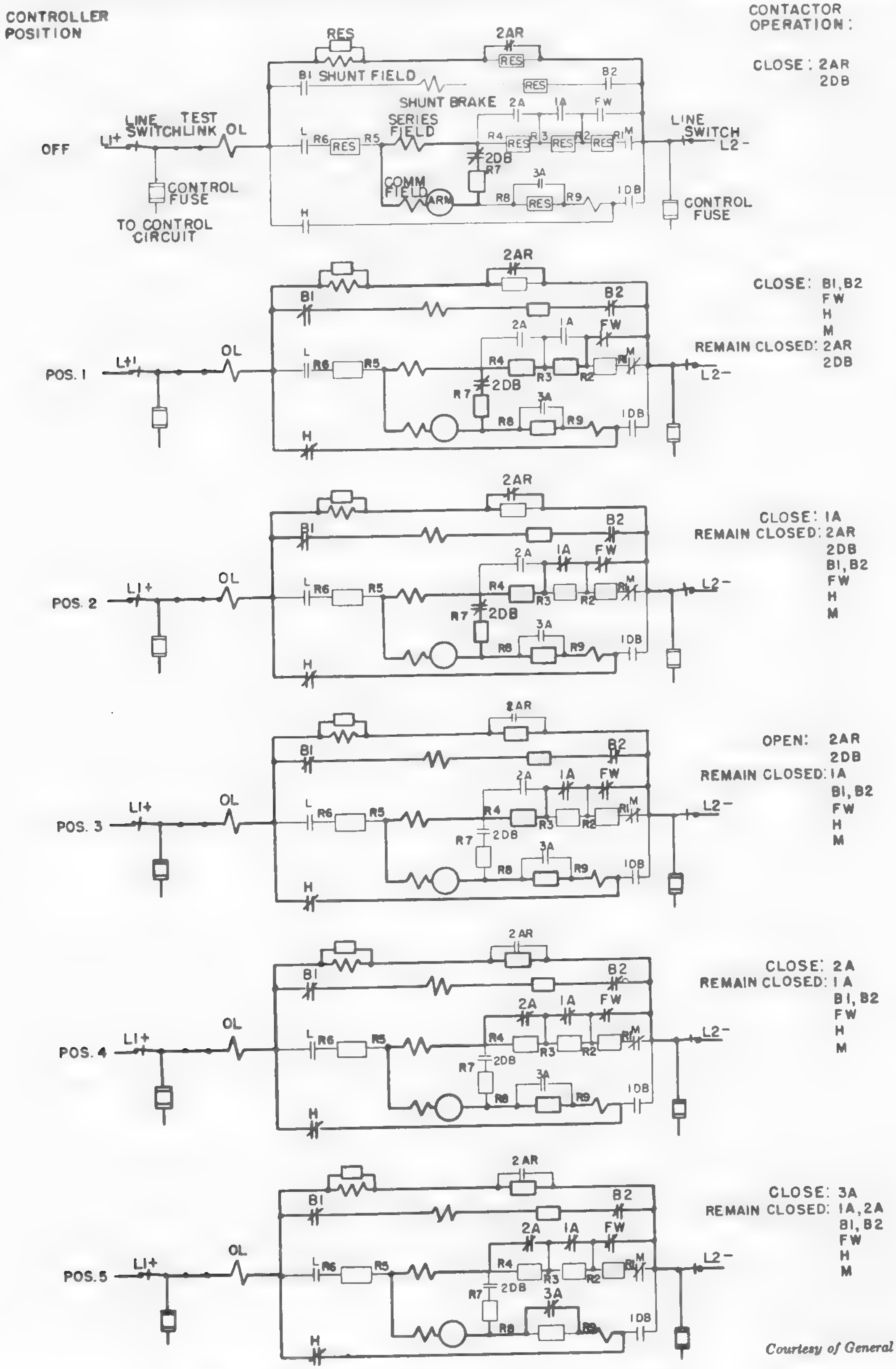


CONTACTORS			
NOMENCLATURE			SYMBOL
M	LINE		CONTACTOR TIP NORMALLY OPEN
H	HOIST	H-L, H-IDB MECHANICALLY INTERLOCKED	
L	LOWER		CONTACTOR TIP NORMALLY CLOSED
IDB			
2DB	DYNAMIC BRAKING		SHUNT COIL
IA	ACCELERATING		
2A			NORMALLY OPEN INTERLOCK
3A			
FW	FIELD WEAKENING		NORMALLY CLOSED INTERLOCK
B1	BRAKE		
B2	BRAKE		

Courtesy of General Electric Co.

RELAYS					
NOMENCLATURE		SHIM	SETTING		SYMBOL
UV	UNDERVOLTAGE	0.060"	PICKUP -145 VOLTS D.O. ABOVE 75 VOLTS		SERIES COIL
DR	DECELERATING	0.010"	0.5	SECONDS TO RELEASE	SHUNT COIL
2AR	ACCELERATING	0.010"	0.5		NORMALLY OPEN CONTACT
OL	OVERLOAD		550	AMP.	NORMALLY CLOSED CONTACT
LR	LOAD		27 OR BELOW	AMP REV. CURRENT LOWERING	INST CLOSING TIME DELAY OPEN CONTACT TO
					INST. OPENING TIME DELAY CLOSE CONTACT TC

Figure 117.—Cargo-winch elementary control diagram.



Courtesy of General Electric Co.

Figure 118.—Power circuit of cargo winch in hoisting position.

aboard cargo vessels. When this equipment is in service, contactors and relays are in a continuous process of opening and closing heavily loaded main power circuits. With the multiplicity of devices and the frequency of their operation, a greater amount of maintenance and trouble-shooting is to be expected on this equipment than is required on the control for any other auxiliaries. The engineering officer will find that the ability to analyze cargo-winch control circuits correctly greatly facilitates maintenance and location of trouble.

The elementary diagram is the main guide in checking a cargo-winch-controller for trouble. Manufacturers use a connection numbering system similar to that shown in figure 117, which simplifies the electrician's job of checking the diagram with actual connections of equipment and operation of devices.

From figure 117 the essential elements of the power circuit are listed as follows:

Line switch—*L1*, *L2*
Line contactor—*M*
Hoist directional contactor—*H*
Lower directional contactor—*L*
Lower dynamic braking contactor—*1DB*
Dynamic braking contactor—*2DB*
Accelerated contactors—*1A*, *2A*, *3A*
Series field-weakening contactor—*FW*
Brake contactor—*B1*
Brake contactor—*B2*
Shunt field-weakening contactor—*2AR*

The power contacts of these devices are opened and closed in various combinations by a multiple-contact master switch, which completes or interrupts the control circuits to relay and contactor coils. This master switch has an "off" position, five positions for hoisting and five positions for lowering. It is mounted on the weather deck near the cargo hatch.

The power circuits which result when the master switch is in the "off" position and in the five hoisting positions are illustrated by the heavy line portion of diagrams in figure 118.

Master switch in "off" position.—When the master switch is in the "Off" position, as shown in figure 117, contacts *MS1*, *MS7*, *MS8*, *MS9*, and *MS10* are closed. With the line switch closed, relays *UV* and *LR* and contactors *1A*, *2AR*, *2A*, and *3A*, are energized. This sets up the effective power circuits shown for the "Off" position in figure 118. Use of these circuits provides dynamic braking through a loop containing the motor armature, commutating field, series field, resistor section *R-7 R8*, and the closed contact *2DB*. The other is the shunt field circuit which is energized in all master switch positions when the line switch is closed. With *B1* and *B2* open the solenoid brake on the motor is de-energized and is set to hold a load by spring action.

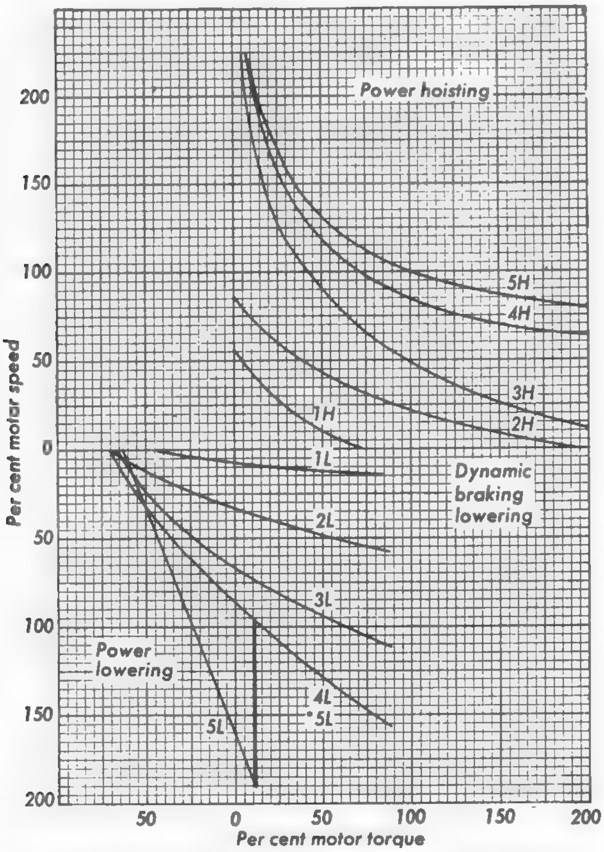
Master switch in position 1 for hoisting.—Master switch contacts *MS3*, *MS6*, *MS8*, *MS11*, and *MS12* are closed. Relay *UV* is sealed in by its auxiliary contact and relay *LR* remains energized. Contactors *H*, *M*, *B1*, *B2*, and *FW* are energized and pickup. Contactor *2AR* remains energized and contactors *1A*, *2A*, and *3A* are de-energized and drop out. This operation sets up the power circuit shown for position 1 in figure 118.

The motor is connected to the line with a resistance *R7-R8* shunted across the armature and with resistance *R2-R3*, *R3-R4*, and *R8-R9* in series with the armature. The brake solenoid is energized and the brake is released. From the speed-torque curves of figure 119 it will be seen that for this position the motor produces about 70 percent normal torque under stalled condition. This torque is sufficient to start a heavy load.

Master switch in position 2 for hoisting.—Contactors *H*, *M*, *2AR*, *FW*, *B1*, and *B2* remain energized, and contactor *1A* is energized and picks up. Position 2 becomes similar to position 1 except that resistor block *R2-R3* is short circuited to provide a starting torque sufficient to start or jog a heavy load.

Master switch in position 3 for hoisting.—Contactors *H*, *M*, *1A*, *FW*, *B1*, and *B2* remain energized, *2DB* is energized and picks up, and *2AR*, is de-energized and drops out. When *2DB* picks up, it opens its normally closed power contact to disconnect the armature shunting resistor *R7-R8*, increasing the armature and series field current. A resistance is inserted in series with the shunt field when *2AR* drops out, and the shunt field current is correspondingly weakened. These circuit changes combine to produce the motor characteristics shown by curve *3H* of figure 119. With the same load on the lifting hook the motor speed is increased.

Master switch in position 4 for hoisting.—The only change which takes place when the master switch is shifted from position 3 to position 4 is that the master switch contact *MS9* closes to energize



Curves 1H, 2H, 3H, 4H and 5H illustrate motor characteristics for the 5 hoist positions of the master switch.

Curves 1L, 2L, 3L, 4L and 5L illustrate motor characteristics for the 5 lower positions of the master switch.

**Curve 5L shows high speed obtainable with a light load on the hook. With a heavy load on the hook the speed is automatically reduced to that of curve 4L.*

Courtesy of General Electric Co.

Figure 119.—Speed-torque curves.

the coil of *2A*. Contactor *2A* then picks up and short circuits resistor block *R3-R4*. This reduction in line resistance increases the voltage applied to the motor and advances the speed-torque characteristic to that shown by *4H* of figure 119.

Master switch in position 5 for hoisting.—This position closes *MS10* to energize contactor *3A*. Contactor *3A* then picks up to short circuit resistor block *R8-R9*, which connects the motor directly to the line advancing the speed-torque characteristic to that shown by the curve *5H* of figure 119.

Notice in figure 117 that with 100 percent torque applied, the master switch must be advanced to position 2 before the load will move. A maximum of 20 percent rated speed will be reached on this position. Similarly, the speeds shown for positions 3, 4, and 5 at 100 percent torque will be the maximums attained for those positions.

The control circuit of figure 117 is arranged to allow suitable time delay between hoisting steps 3, 4, and 5, even if the operating handle of the master switch is quickly placed in the fifth position. This is accomplished by the *2AR* relay, which has time delay for opening after being de-energized. Accelerating contactors *2A* and *3A* cannot, therefore, be energized in the fourth and fifth positions until *2AR* has timed out.

Lowering.—Lowering with a cargo winch is a different problem from hoisting. Power is required only when unreeling a light line or providing the necessary break-away torque to start a load. The rest of the control operation involves the use of the motor as a generator to slow down overhauling loads dynamically by dissipating the generated energy through resistance.

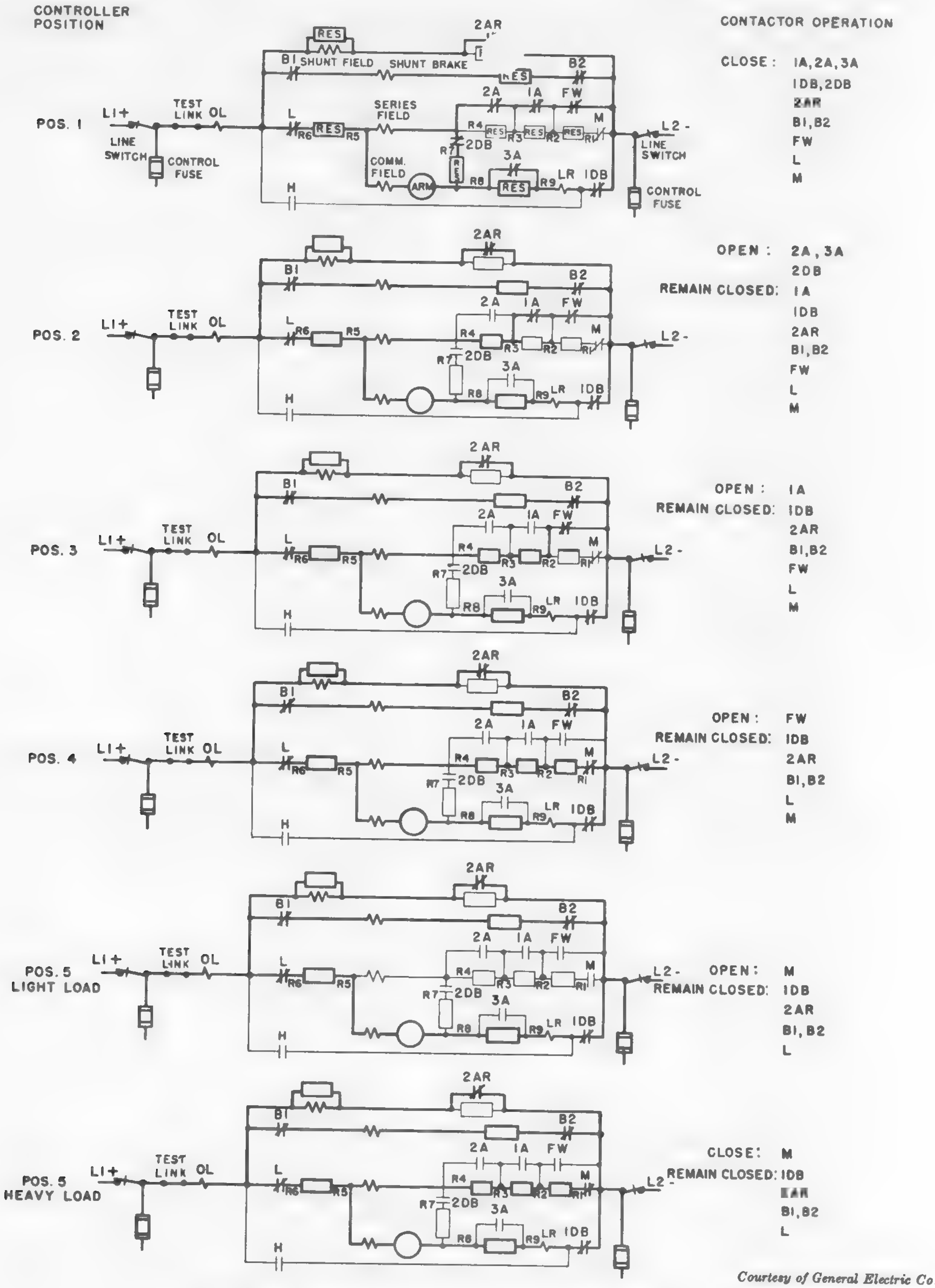
In the lowering direction the series field is connected in shunt with the armature to provide a strong field excitation for effective dynamic braking with overhauling loads and safe running speed for light loads. The normal shunt field is connected directly across the line in all lowering positions for additional field excitation.

To permit higher speeds in the lowering direction, the motor must be made less effective as a generator. This is done by inserting resistance in the series field circuit to decrease the over-all field excitation. For fast power lowering of light loads the series field is automatically disconnected in the fifth position, leaving only the shunt field to provide field excitation. The series field is automatically reinserted in the fifth position if the load is sufficient to overhaul the motor.

Power circuits are set up for the five lowering positions, as shown in figure 120.

Master switch position 1 for lowering.—When the master switch is moved into position 1, as in figure 117, relays *UV* and *2AR* and contactors *M*, *L*, *1A*, *2A*, *3A*, *1DB*, *FW* are energized. This results in power circuit connections as diagrammed in figure 120.

A line resistor *R5-R6* is connected to the armature series field parallel combination, and resistor *R7-R8* is inserted for dynamic braking. The resulting speed-torque characteristic is shown in



Courtesy of General Electric Co.

Figure 120.—Power circuits of cargo winch in lowering position.

figure 119. The percent rated motor speed is sufficiently low in both power lowering and dynamic braking lowering to stop the load quickly in the "Off" position with the solenoid brake.

Master switch in position 2 for lowering.—With the master switch in position 2, *MS5* (see figure 117) closes to energize *2DB* and *MS10* opens to de-energize contactors *2A* and *3A*. In the power circuit, *2DB* opens a normally closed contact to remove the dynamic braking resistor *R7-R8*; the *2A* contact opens to insert the resistance *R3-R4* in the series field circuit; and the contact *3A* opens to insert resistor *R8-R9* in the armature circuit.

As the student has learned from his study of d-c motors and generators in preceding chapters, this weakening of the field excitation will reduce the effectiveness of the motor as a generator for dynamic braking, permitting an overhauling load to assume the higher speed characteristic, as shown in figure 119. The weakened field also results in a higher speed characteristic when lowering a light load with power.

Positions 3, 4, and 5 are successive operations to reduce further the field excitation and permit higher speeds with powered and overhauling loads.

Master switch in position 3 for lowering.—Master switch contact *MS7* opens, de-energizing contactor *1A*, which opens its power contact to add the resistor *R2-R3* to the series field circuit.

Master switch in position 4 for lowering.—Master switch contact *MS11* opens de-energizing contactor *FW* which opens its power contact to add resistor *R1-R2* to the series field circuit.

Master switch position 5 for lowering.—Master switch *MS6* opens to de-energize contactor *M*. The *M* contact opens in the power circuit to disconnect the series field. If, however, the load is heavy enough to overhaul the motor, a step-back relay *LR* closes a normally closed contact in the control circuit to re-energize the *M* contactor and return the power circuit to the same condition obtained in position 4.

From figure 117 it will be seen that the *LR* relay has a coil in the control circuit and a series coil connected in the motor power circuit. When the motor is acting as a generator with overhauling loads, the direction of current in the series coil of *LR* results in a magnetic field which opposes that of the coil in the control circuit.

When the generated current reaches a certain value, this opposing magnetic field causes the relay to drop out. This operation accomplishes the step-back feature for position 5 as described above.

Decelerating relay DR.—The relay *DR* establishes a dynamic-braking circuit prior to the setting of the brake when the master switch is moved rapidly from position 3, 4, or 5 lowering to the "Off" position.

In figure 117 notice that relay *DR* is energized in lowering positions 3, 4, and 5 through a normally closed contact of *1A*. When the master switch is returned to the "Off" position, contactor *1A* is energized in positions 1 and 2 and opens its normally closed contact in the *DR* coil circuit to de-energize this relay. This relay however times out, permitting a time delay of about one-half a second before its contacts open to de-energize *1DB*, *2DB*, *FW*, *B1*, and *B2*. Note that *2DB* would be normally de-energized in position 1, whereas contactors *1DB*, *FW*, *B1*, and *B2*, would be de-energized in the "Off" position.

Emergency switch.—An emergency switch mounted on the master switch enclosure can be used to break immediately the control circuit to the holding coils of the contactors and allow the brake to set. After the emergency switch is so operated the control must be reset for further operation of the motor by moving the master switch handle to the "Off" position. Connection of the emergency switch is shown in the diagram of figure 117.

Since cargo-winch control is typical for control of practically all deck machinery, the student will find that a good understanding of the detailed operation given above will provide sufficient background for analyzing the controls for capstans, windlasses, and various d-c motor-powered hoists.

Capstan control, for example, provides selective speed in either direction. The accelerating contactors are automatically timed to provide smooth acceleration and to prevent the accelerating current from becoming excessive. Obviously there is no necessity for dynamic braking since there is no problem of overhauling loads. Motor torque is limited by the use of step-back relays to prevent line breakage.

Most anchor windlasses provide, in addition to their function of raising and lowering the anchors, a capstan head that can be used for warping the ship to the pier. A dual control required for the motor provides dynamic braking for the anchor lowering and can be converted to the equivalent of capstan control for warping duty.

D-C Control Devices

Contactors.—Direct-current contactors differ from a-c contactors in design of magnetic elements and main contacts. With d-c contactors there is no need for the laminated core used with a-c contactors to prevent eddy currents. Alternating-current contactors are also built with a shaded or short-circuited coil on the face of the magnet to prevent the armature from dropping out when the magnetic field passes through zero during an alternation of current. This feature is obviously not required for contactors operating on direct current. The design of contacts varies because of the difference in behavior between alternating current and direct current under circuit interrupting conditions.

The maintenance routine for d-c contactors is practically identical with that already given for a-c contactors. Special attention, however, should be given to those contactors operating with deck machinery and hoisting applications where the frequency of opening and closing is considerable during the period in which the equipment is in use. A good maintenance program on these contactors should be carried out while the ship is at sea for reasonable assurance that they will operate satisfactorily when needed in port.

Relays.—It has been shown in the preceding discussion that relays play an important part in the functioning of d-c control circuits, particularly when applied to deck machinery.

Some of their main purposes are outlined as follows:

1. *Low-voltage protection.*—There are a number of control circuits that require a separate relay for low-voltage protection. These include circuits designed for automatic pressure switch or float switch operation in combination with hand operation and practically all deck-machinery control circuits. A typical general service relay used for under-voltage protection is shown in figure 121. These relays require very little maintenance, and if they are given proper routine cleaning and inspection, they are very inapt to cause trouble.

2. *Overload protection.*—Magnetic and thermal overload relays of various types are employed with d-c starters for motor protection. Magnetic overload relays are provided for instantaneous tripping or for inverse time-delay tripping. These relays are actuated by a coil connected in series with the line to be protected. The normally closed contacts

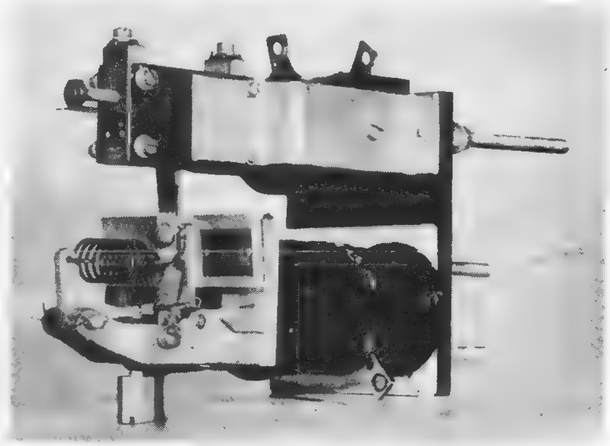


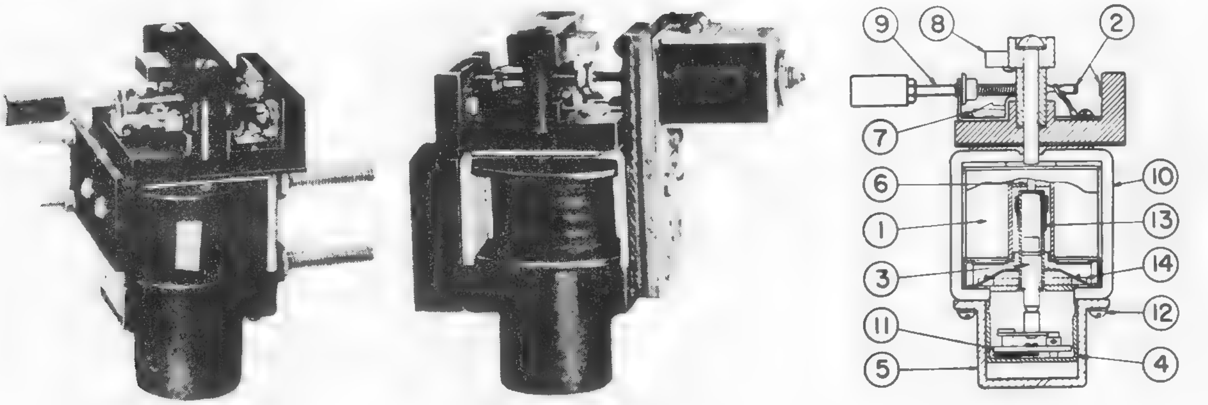
Figure 121.—General service single-contact-type relay.

are usually connected in series with the coil of the line contactor. When the current in the relay coil exceeds normal-load current, the magnetic force exerted on an iron plunger pulls it upwards. If the relay is of the instantaneous type there is little restriction to the movement of the plunger and the relay contacts open almost immediately. With the inverse time-delay type, however, the plunger is attached to a disk or dash that moves in a dashpot of oil. As the plunger moves upwards, the disk encounters the resistance of the oil and time delay is introduced, this time delay depending on the force imposed on the plunger by the relay coil.

Figure 122 illustrates a typical magnetically operated inverse time-delay relay. When the current in the relay coil (1) exceeds normal-load current, the magnetic force exerted on the iron plunger (3) pulls it slowly upward through the oil in the dashpot (4). When the iron plunger hits the top of the dashpot, the magnetic force pulls the oil dashpot assembly (4) upward through the outer air cup or guide cup (5). This action moves the trip pin (6) and the lever mechanism (7), allowing the normally closed contacts (2) to snap open. This breaks the control circuit to the line contactor thereby disconnecting the motor from the line.

Instantaneous relays are used with such applications as deck machinery where it is necessary to stop the motor on overloads, even though they are of short duration, and to have power restored immediately after the overload condition is removed.

Thermal relays are used with the majority of below-deck auxiliaries which normally run at a constant speed. They utilize a bimetallic strip heated by a coil that carries motor current. When the



With Manual Reset

With Automatic Reset

1. Coil
2. Contacts
3. Plunger
4. Dashpot Assembly
5. Guide Cup
6. Trip Pin
7. Trip Lever Mechanism
8. Inertia Latch
9. Reset rod
10. Frame
11. Dash
12. Guide Cup Screws
13. Rating Adjuster
14. Cross Bar

Courtesy of Westinghouse Electrical Corp.

Figure 122.—Magnetically operated inverse time-delay overload relay.

bimetallic strip is sufficiently deflected by the effect of overload current in the heater coil, it trips a latch that opens a set of normally closed contacts. The relay is equipped with a knob which when pressed resets the latch to close the contacts. Resetting cannot be accomplished, however, until the bimetallic strip has had sufficient time to cool down.

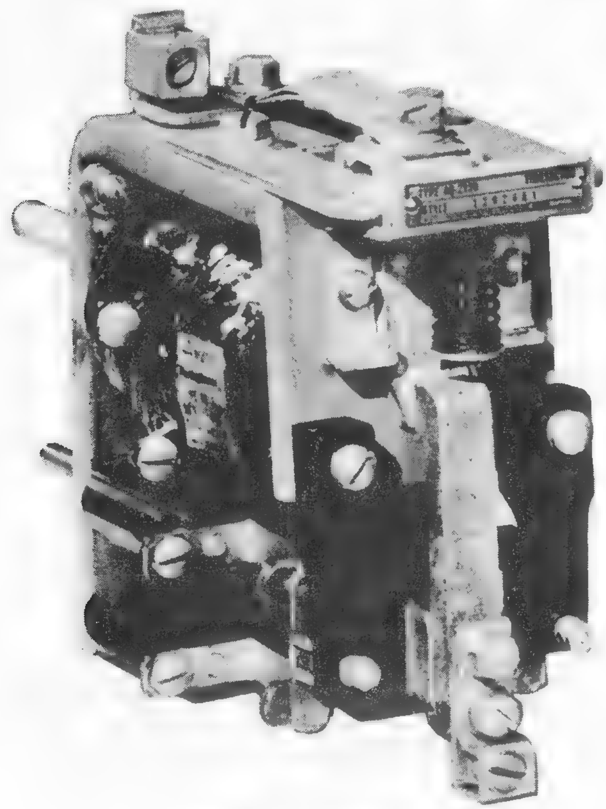
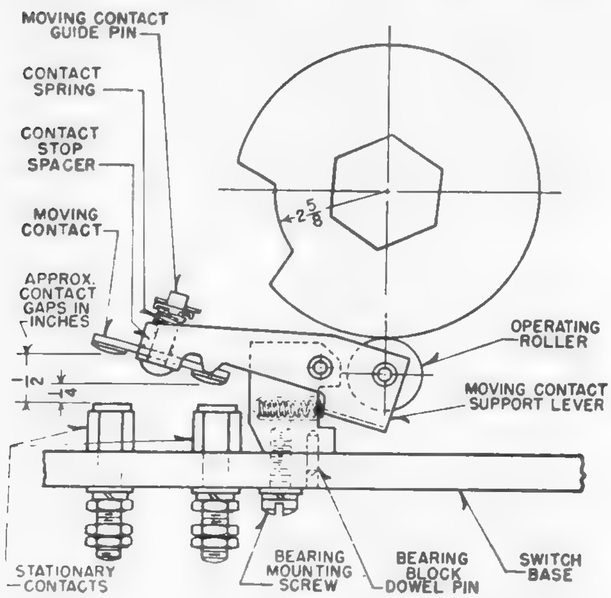


Figure 123.—Step-back relay.

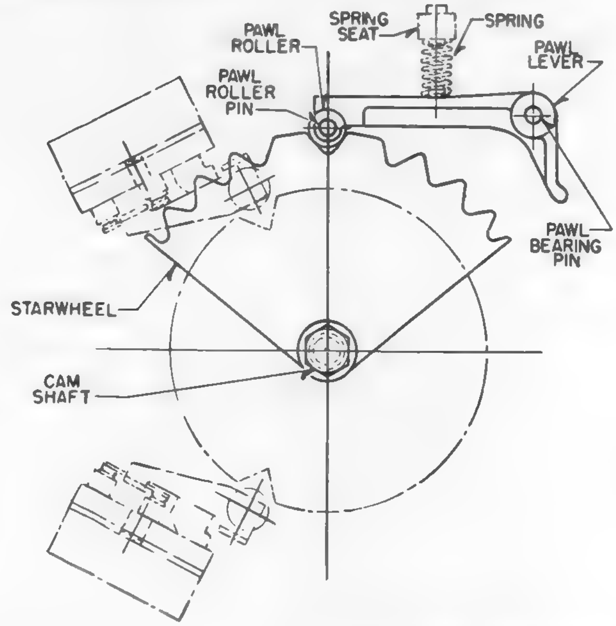
3. *Step-back relay.*—One type of step-back relay used with cargo-winch control operates on the following principle. The operation of the relay is dependent upon a series coil connected in the motor circuit, a shunt coil connected in the control circuit, and an operating spring. In a typical cargo-winch control, the series coil is connected to set up a magnetic field which opposes that of the shunt coil when the motor is operating as a generator for dynamic braking. Under these conditions the relay will drop out at a predetermined value of motor current, and a normally closed contact in the control circuit will close to re-establish the power circuit of the previous lowering step. When the motor is furnishing mechanical power to hoist a load or lower a light load with power, the series coil magnetic field aids that of the shunt coil and the relay contact remains open.

There are several variations of this type of relay, depending on the application. With capstan control, for example, the step-back relay is used to limit the motor torque to prevent line breakage, and its operation is not contingent on reverse current as is the requirement with cargo-winch control. In this application when normal current is flowing in the series coil, a spring holds the relay in its normal position. When the series coil current



Courtesy of Westinghouse Electrical Corp.

Figure 124.—Master-switch cam and roller assemblies.



Courtesy of Westinghouse Electrical Corp.

Figure 125.—Master-switch starwheel, paul and roller assembly.

reaches a predetermined value, the relay trips and a circuit is established; thus the shunt coil in the control circuit becomes energized. This coil sets up a magnetic field which opposes that of the series coil. When the relay trips, its contacts in the control circuit act in conjunction with accelerating contactors to re-insert all line resistors into the armature circuit; this reduces the voltage applied and the motor torque. When the current in the series coil drops to a certain value, an operating spring forces the relay armature to drop out. Power circuit connections are automatically restored to correspond with the master switch position. A typical step-back relay is shown in figure 123.

Maintenance of relays.—The maintenance of relays follows the same procedures outlined under a-c control. The coils, contacts, and other parts are arranged to permit easy access for replacement. Many designs are complete unit assemblies so that an entire unit may be quickly replaced by another one.

The operator is again cautioned not to lubricate bearings except on rare occasions and then only with a small amount of light machine oil. Bearings are designed to operate without lubrication.

With thermal relays it should be noted that the bimetallic strips are carefully calibrated for each individual application and, therefore, should not be tampered with. No bending of the strip should ever be made to change calibration or to attempt correction of a defective relay.

In replacing coils of relays, see that connections are made in exactly the original manner.

The same care of contacts should be exercised with relays as for contactors except that considerably less maintenance is to be expected with relay contacts where the contact current is usually only a fraction of an ampere.

Cam-operated master switch.—The master switch for capstan, winch, and windlass control is pedestal-mounted in a watertight enclosure, as illustrated in figure 129.

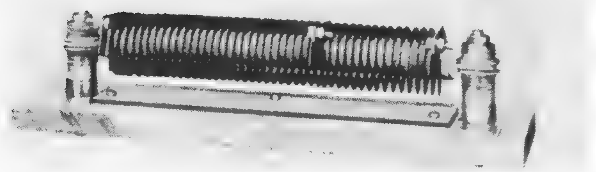
The contacts of this type master switch are operated by a series of cams and rollers in an arrangement as shown in figure 124.

For a master-switch assembly, a number of switch units are usually mounted on an insulating base. The switch units are operated by phenolic cams mounted on a hexagonal steel shaft that is mounted parallel to the switch bases. The switch unit contacts or circuits open or close as the shaft is rotated, the sequence of operation being determined by the shape of the cams and their location on the shaft.

A starwheel and roller assembly, as shown in figure 125 provides definite positioning of the cam shaft at various operating points. The operating

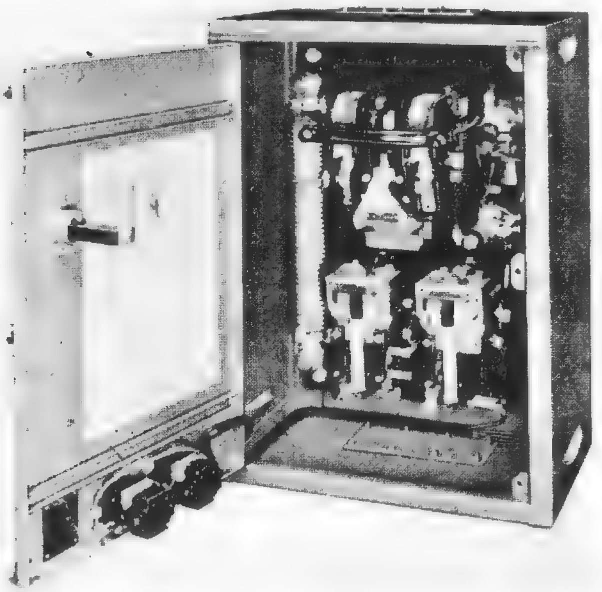
Courtesy of Westinghouse Electrical Corp.

Figure 126.—Wire-wound resistor.



Courtesy of Westinghouse Electrical Corp.

Figure 127.—Edge-wound resistor.



Courtesy of Westinghouse Electrical Corp.

Figure 128.—Direct-Current starter.

handle is held by the starwheel and roller assembly in any position selected until the operator moves it to another position.

Maintenance.—A periodic check should be made to insure that all screws, bolts, and nuts are tight. All current-carrying parts should be kept clean and tight.

When excessive burning and pitting of contacts takes place, the contact pressure should be checked. This should be approximately 1 pound total for the two contact buttons.

It is important that the gap between moving and stationary contacts be kept within limits as prescribed by manufacturers. This also applies to the overtravel or the distance that a moving contact would travel if it were not stopped by the stationary contacts.

Clean contactors, using the same precautions prescribed for contactors and relays with silver contact tips. If either stationary or moving silver contact buttons wear or burn down to $\frac{1}{32}$ inch from the brass or steel contact support, the contact should be immediately replaced. Brass or steel are poor contact materials and will cause overheating.

Resistors.—A resistor unit is generally rated in the amperes it can carry continuously, or in the watts it can dissipate indefinitely without the temperature rise exceeding a safe value.

With d-c motor starting or accelerating applications, however, the resistor assemblies are designed on an intermittent rating basis. Intermittent ratings are determined by measuring the temperature rise after completion of a certain number of operating cycles in actual test.

Resistors vary in the type of construction, depending on the size required. Small resistors consist of a wire element wound on a refractory insulating tube, with the complete assembly sealed and coated with vitreous enamel. Such resistors are mounted integrally with starters for small d-c motors. A typical wire-wound resistor is shown in figure 126.

A common type of resistor designed for high currents consists essentially of an edge-wound resistance element, a heat treated steel mounting bar and insulator support, and a set of refractory insulators. Figure 127 shows an assembly of this type resistor.

Edge-wound resistors are commonly used for starting, accelerating, and dynamic braking with capstan, windlass, and winch motors. For these applications a number of resistor units are assembled in one frame, as shown in figure 129. With large motors several frames of the resistors are used with a single control panel.

Resistors for deck machinery are generally mounted inside a deck house with their corresponding control panels.

Maintenance of resistors.—All current-carrying connections should be clean and fastened as tight as

possible to avoid overheating at the joints. Compressed air should be used periodically to remove accumulations of dust and dirt that collect on resistors and connectors. Individual resistor tubes can be easily removed from the frame assemblies for replacement when damaged.

General Construction of D-C Motor Starters

With most starters for below-deck auxiliaries the resistors are mounted inside the enclosure with the control devices. Control devices are mounted on an insulated panel and are interconnected with wiring on the back of the panel.

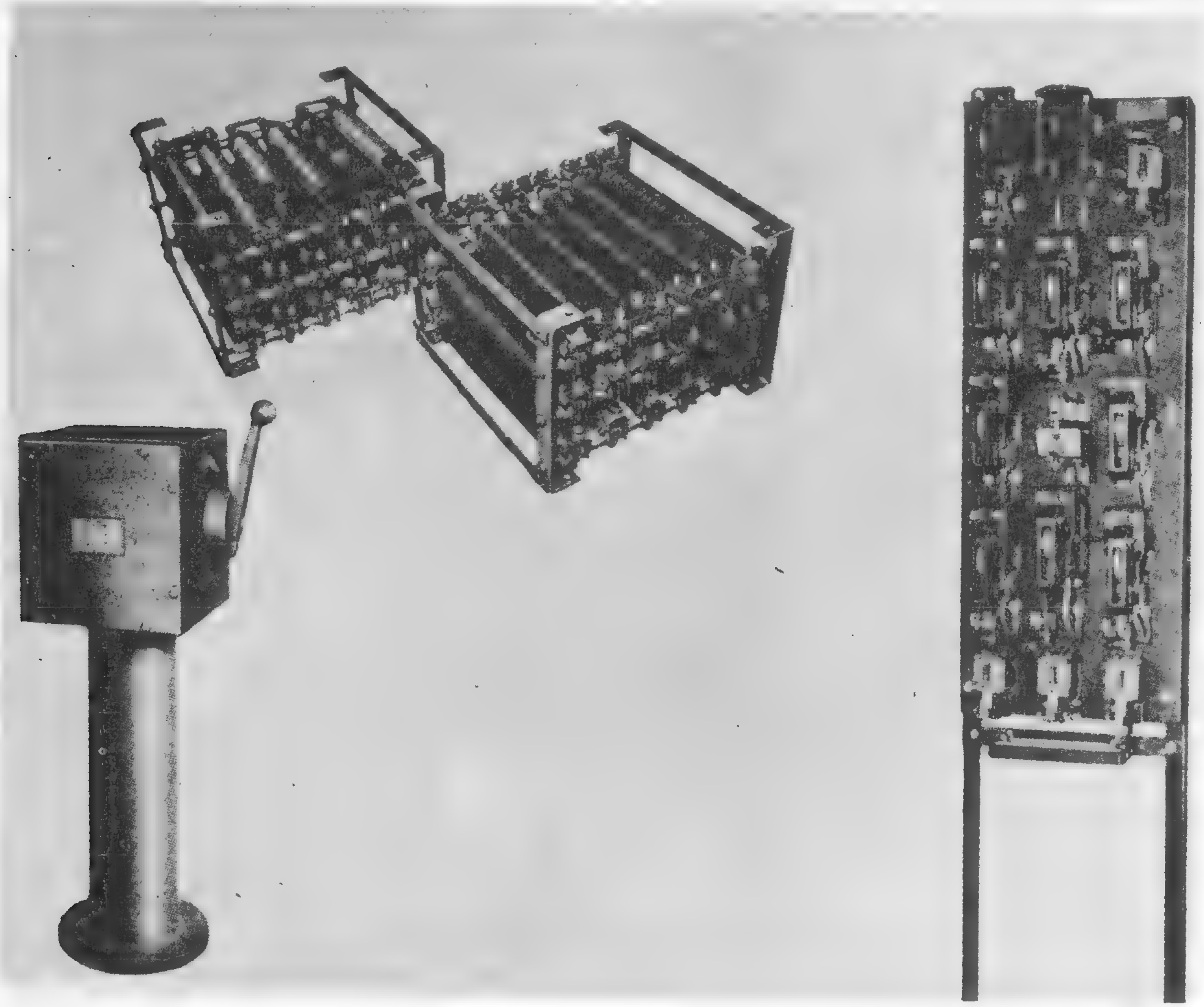
Control panels are mounted in metal enclosures built to the requirements of Navy specifications for either drip-proof, spraytight, or explosion-proof service. These types of enclosures have been previously illustrated under a-c starters.

Standard removable plates for incoming loads are provided at both the top and bottom of the enclosure.

Some starters have the push-button station mounted on the enclosure door so that it is an integral part of the equipment. Overload reset buttons are usually mounted on the enclosure door, so that when the door is closed, they engage the reset mechanism of the overload relay.

A typical d-c starter is shown in figure 128.

Open type panels are generally used with cargo winch, capstan, and windlass controls. These are mounted on angle iron frameworks which are ordinarily bolted to the deck inside of a watertight deck



Courtesy of Westinghouse Electrical Corp.

Figure 129.—Cargo-winch control consisting of master switch, resistors, and control panel.

house. Cargo-winch control panels are usually bolted together to form a compact group within the deck house. A single open-type cargo-winch control panel is shown in figure 129.

Maintenance of Complete Controllers

All possible safety precautions should be taken when servicing control, not only at the panel itself but at the distribution board, the feeder lines, the motor, and the driven machines.

Periodic inspections will save time and often avoid expensive replacement of complete apparatus under breakdown and emergency conditions. Accumulations of dirt and dust should be blown out with compressed air; but where compressed air is not available, careful cleaning may be sufficient. Oil and moisture should be eliminated at all times.

In the course of inspection all moving parts should be tried by hand to locate loose pins, nuts, and bolts. All parts should move freely without excessive friction. Special attention should be given to those devices subject to wear and change in adjustment owing to vibration.

Insulation should be checked for leakage circuits which may develop as a result of the accumulation of moisture, oil, or dirt. Where insulation shows evidence of damage as a result of rubbing against other parts, the cause of this damage should be immediately removed and the insulation repaired.

Excessive heating is always a sign of trouble. Some parts are designed to operate at temperatures uncomfortable to the bare hand, but this is usually confined to resistors. A smoking part should receive immediate attention.

Loose connections can be an annoying source of trouble, and they are sometimes difficult to locate on large control panels. A periodic tightening of all connections will generally prevent loose connections from developing.

Regular insulation tests with a megger should be conducted to eliminate possible grounds. Existing grounds can cause unexpected and incorrect motor operation. Grounds are commonly caused by faulty insulation and accumulations of water at connections.

Trouble-shooting.—The methods used for locating trouble in control circuits has been previously discussed in the section on a-c motor starters; identical procedures can be used with d-c control. The more complex control circuits applied to deck machinery, however, are deserving of special attention.

There is no set procedure for locating a defective control part on a deck machinery control panel. The electrician experienced with this type of control can usually spot a defective contactor or relay without consulting the wiring diagram, by simply operating the auxiliary on all positions of the master switch. Certain fundamental considerations, however, are outlined below, which may prove helpful to operating engineers in supervising less experienced personnel.

Cargo-winch control is again taken as an example for this discussion, and the reader is referred to figures 117, 118, and 120.

If the winch fails to start when the master switch is moved from the "off" position to several points "Hoist" or "Lower," the availability of power should be checked, including power at the main switchboard, distribution panel, and terminals of incoming lines at the control panel. If there is power at the control panel but the under-voltage relay is not picked up, control fuses and the condition of the overload relay should be checked.

The next step is to check operation of the line contactors N, L, and H, by moving the master switch through all positions "Hoist" and then through all positions "Lower." The motor should be either disconnected from the control panel or declutched from the winch drum during these tests and most of those that follow. If any one of these contactors fail to close, the line switch should be opened and the corresponding master-switch contact *MS2*, *MS3*, or *MS6* checked with an ohmmeter for proper sequence of opening and closing.

Trouble will occasionally develop where a motor will fail to develop the necessary torque to raise an average load at the speeds normally attained for certain positions of the master switch. This is usually due to the failure of an accelerating contactor, *1A*, *2A*, or *3A*, to operate. This trouble can be first isolated by putting the master switch in the position in which incorrect operation occurs and then checking the position of main contacts in the power circuit against power diagrams similar to figure 118. When the contactor that fails to close has been located, circuit continuity to the contactor coil can be checked by using an ohmmeter across the master switch and auxiliary contacts in the coil circuit. This procedure will follow for any other master switch positions that show evidence of incorrect performance.

CHAPTER 10

SHIP'S SERVICE AND EMERGENCY LIGHTING

Lighting Distribution Systems

Lighting distribution systems on combat ships can be divided into two classes: ship's service and emergency. Under normal conditions all lighting circuits are energized from the ship's service power supply. Certain designated circuits, however, are arranged with automatic bus-transfer equipment which connects them to an emergency supply when there is a failure in the ship's service power supply.

Ship's Service Lighting System

Feeders for the ship's service lighting system emanate from ship's service switchboards or on the larger vessels from lighting-load center units connected directly to the switchboards. The feeders supplying lighting for machinery spaces, boiler rooms, steering-gear room, and other spaces in the vicinity of switchboards or lighting-load center panels are generally connected to a 117-volt, three-phase bus at the local main switchboard. Feeders to distribution panels which are remotely located with respect to switchboards or lighting-load center panels are connected to 450/117-volt transformers which are supplied by the 450-volt, three-phase bus. Special systems, such as running, signal, anchor, and fighting lights, are generally served by feeders from the 117-volt bus.

The 117-volt bus of a switchboard or lighting-load center unit is connected to the 450-volt bus through a bank of single-phase air-cooled transformers connected in delta on both the primary and the secondary side. This connection permits operation in open delta at 58 percent capacity in the event of a failure to a single transformer. Each transformer bank is generally located near the switchboard or lighting-load center unit for convenience in making the bus interconnections.

The 450-volt feeders serving distribution panels in the more remote areas of the ship are connected to the panels through similar 450/117-volt transformer banks located in those areas. The feeder is thus subdivided at the distribution panel into several 117-volt, three-phase circuits, and these in turn are further subdivided by other panels and distribution boxes before actual connection to lighting fixtures.

Lighting-fixture circuits are single phase and are generally the only single-phase circuits in the lighting system. The proper connections of these circuits for three-phase balance is made within the distribution boxes which supply these circuits.

The extent to which subdivision of lighting circuits is carried out on the larger combat ships is illustrated in the schematic diagram in figure 130. It should be realized, however, that this diagram represents only a small portion of an actual lighting installation.

Emergency Lighting System

The emergency lighting system includes emergency feeders from emergency switchboards, bus-transfer units, and all lighting circuits which, by virtue of their interconnection with bus transfer units, can be supplied from either ship's service power or emergency power.

Emergency feeders emanate from an emergency switchboard, 117-volt, three-phase bus. This bus is connected to the respective emergency switchboard, 450-volt bus through a bank of single-phase transformers similar to those discussed under ship's service lighting distribution.

Bus-transfer units are installed throughout the ship in convenient locations with respect to the

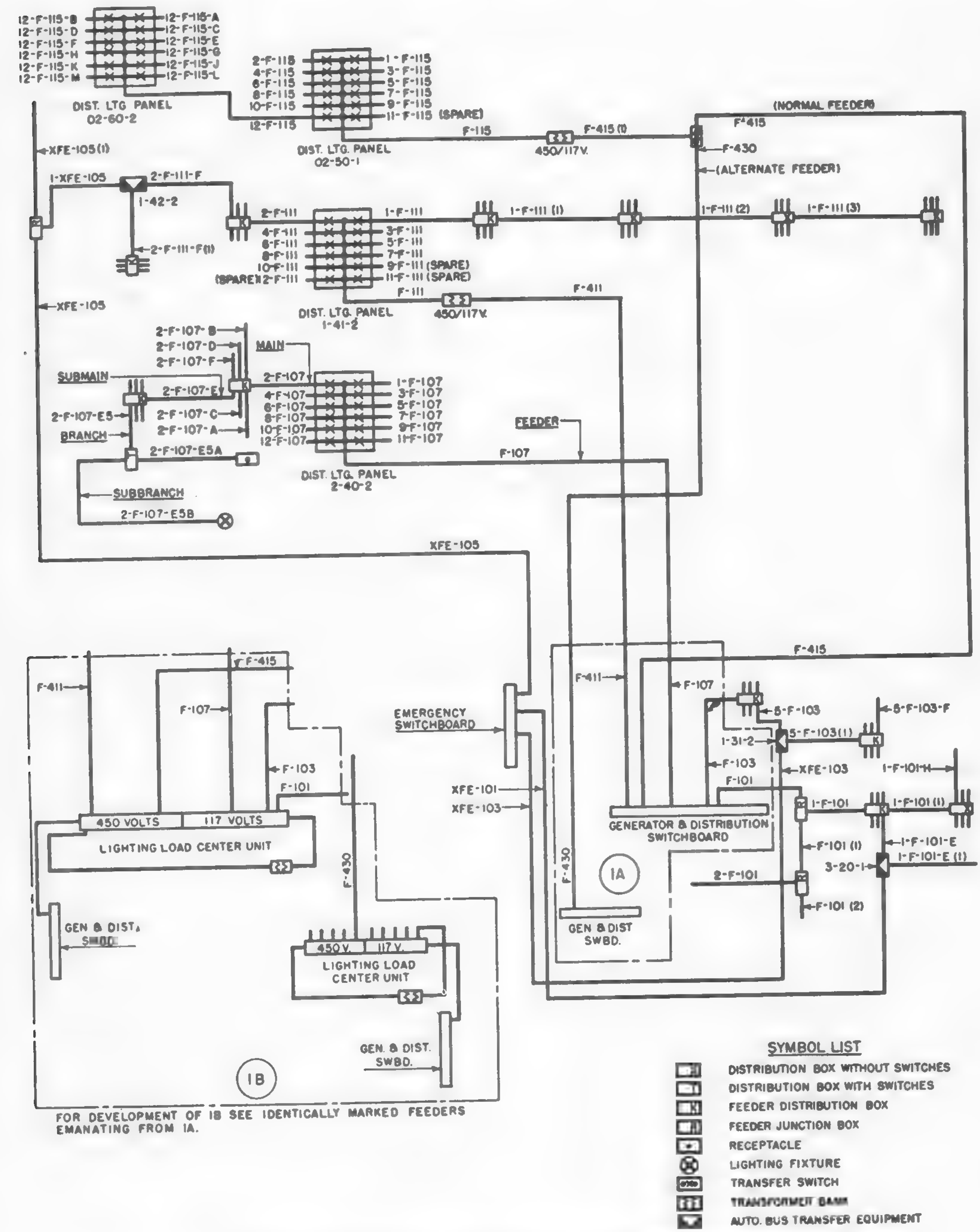


Figure 130.—Schematic diagram of typical ship's service lighting distribution.

emergency lighting areas they serve. Each unit includes two solenoid-operated contactors that operate in conjunction with a voltage-sensitive relay to switch automatically a connected load from a ship's service supply to an emergency supply when there is power failure on the ship's service supply. The ship's service supply to a bus transfer unit is generally from a distribution panel, whereas the emergency supply is provided by an emergency feeder direct from the emergency switchboard. The interconnection of a bus transfer unit in a lighting distribution system is illustrated by the typical schematic diagram in figure 131.

With the exception of certain living spaces and storage spaces, emergency lighting on combat ships is provided in all compartments and for all services where a continuous power supply is essential to the fighting efficiency of the ship. The extent to which the lighting circuits in a space are provided with emergency supply is dependent on the character of the work performed in that space and its importance to the performance of the ship as a fighting unit.

Special services that require emergency lighting include running and signal lights, operating table, standard compass illumination, 12-inch searchlight, flight-deck lighting, and many others.

Cable Marking and Identification

The lighting system employs essentially the same scheme for cable identification as the power system discussed in chapter 2. The two principal identifications for lighting cables are "F" to denote ship's service lighting feeders and "XFE" to denote emergency-lighting feeders. The numbering system for lighting feeders is identical to that used for power feeders, with odd numbers being assigned to those connected to forward switchboards or lighting-load center units and even numbers for those connected to after switchboards or load center units. On vessels with only a single switchboard, this system is modified by assigning odd numbers to feeders running in a general forward direction and even numbers to those running in a general aft direction.

The numbers following a feeder designation are indicative of the voltage; for example, a feeder marked F–105 is a 117-volt circuit, and one marked F–437 is a 450-volt circuit.

Lighting feeders are subdivided into mains

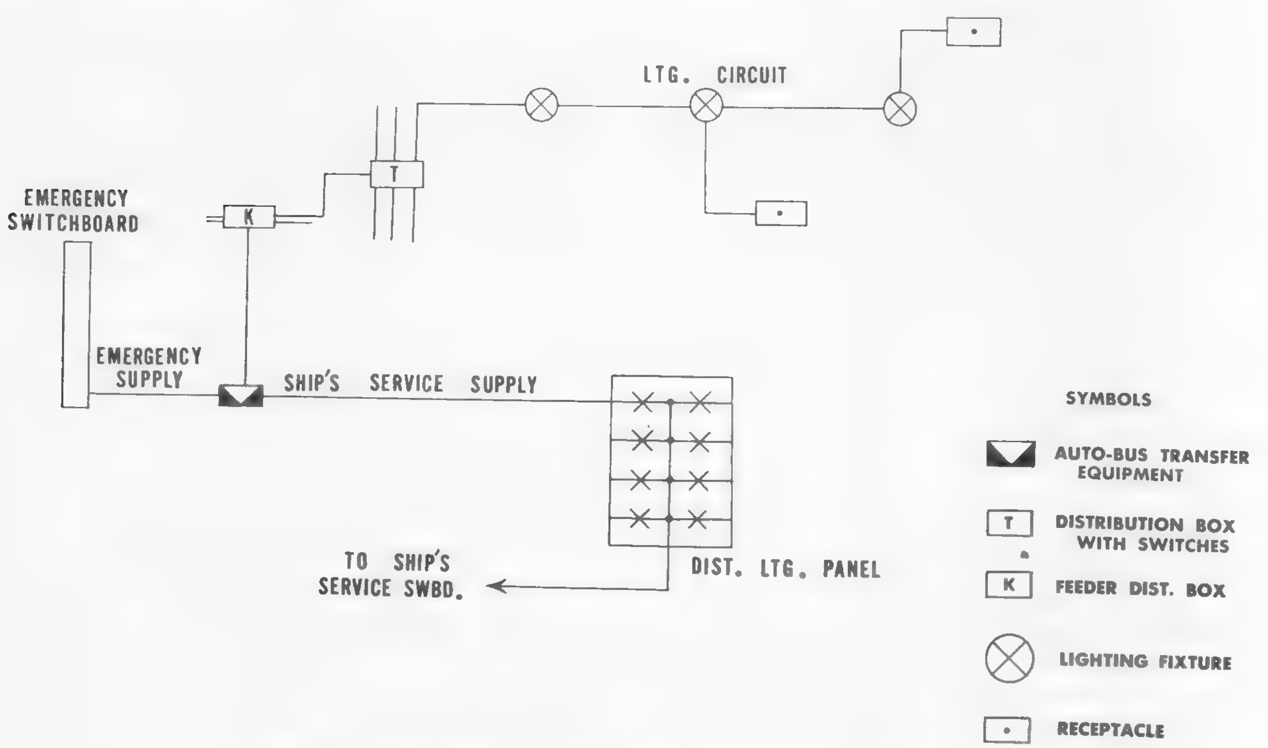


Figure 131.—Schematic diagram of lighting bus-transfer connections.

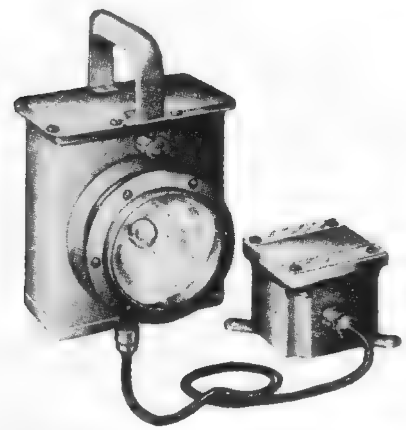


Figure 132.—Relay-operated hand lantern.

submains, branches, and sub-branches in much the same manner as power feeders. The system of numbering these subdivisions is the same as that outlined for the power system in chapter 2. Figure 130 shows how this numbering system is applied.

Relay-Operated Hand Lanterns

In the event of a failure in both the ship's service lighting supply and the emergency supply, an insurance against total darkness is provided by battery-powered hand lanterns, which are automatically turned on by relay control. These lanterns are installed in certain strategic locations, such as essential watch stations, control rooms, machinery spaces, battle dressing stations, accesses, and companionways, where it is necessary to maintain practically continuous illumination.

The relays for these lanterns are connected ahead of the lighting-control switches that control the spaces where they are installed, so that turning off the switch will not energize the relay-controlled lantern. In the event of failure to both ship's service and emergency supply, however, the lantern relays drop out, completing the battery circuit and providing an instantaneous source of illumination.

Manually Operated Hand Lanterns

Battery-powered hand lanterns identical to those described above but not connected to relays are installed as an emergency source of illumination in stations manned only occasionally where instantaneous illumination is not essential. Manually operated hand lanterns are also provided in spaces where relay-operated lanterns are installed to supplement that illumination as required.

A relay-operated hand lantern is illustrated in figure 132.

Lighting fixture are designated according to the enclosure in which they are used as *watertight*, *nonwatertight*, *pressure-proof*, or *explosion-proof*.

Watertight fixtures are used in all spaces subject to a high moisture content, such as certain machinery spaces, boiler rooms, and pump rooms. They are also installed in all exposed spaces and on weather decks. Nonwatertight fixtures are used in spaces that are ordinarily dry, such as living spaces, storage spaces, and workshops. Explosion-proof fixtures are installed as general illumination for all compartments where dope or gasoline is handled or stowed and in other spaces subject to explosive air mixtures. The chief application for pressure-proof fixtures is for the emergency lighting system on submarines.

Lighting Equipment

Classification of Fixtures

Lighting fixtures are classified with reference to their use as follows:

1. *Regular fixtures, permanent.*—These fixtures are permanently installed and are used to provide general illumination and such illumination as may be required in specific locations.

2. *Regular fixtures, permanent (red lights).*—These are permanently installed fixtures having red globes. They are used to produce low-level red illumination.

3. *Regular fixtures, portable.*—These fixtures are used for such lighting applications as cannot be served by permanently mounted fixtures. They are energized by means of portable cables plugged into outlets in the ship's service wiring system.

4. *Miscellaneous fixtures.*—This classification includes a variety of fixtures used for the most part for detail and special lighting applications not served by regular permanent or portable lighting fixtures.

5. *Running, anchor, and signal lights.*—In gen-

eral, this classification includes all external lights (except searchlights) used for navigational and signaling purposes between vessels to prevent collisions and to transmit intelligence while moving or at anchor.

6. *Lights for aircraft carrier night-flight operations.*

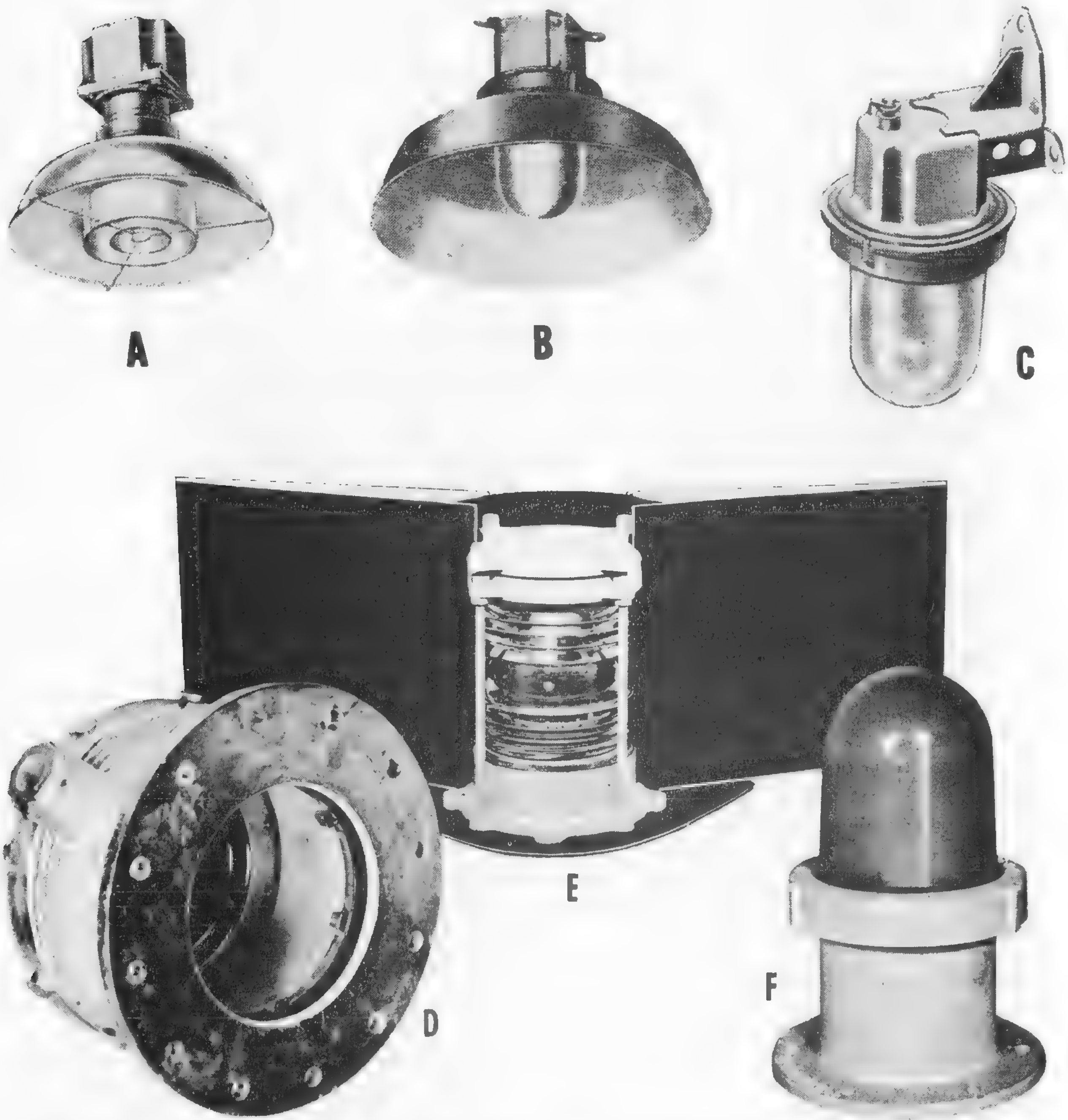


Figure 133.—Typical regular permanent lighting fixtures—(A) Ceiling fixture N.W.T. 50 w; (B) Deck fixture W.T., 50 w; (C) Bulkhead fixture W.T., 50 w; (D) Bulkhead fixture, explosion-proof, 50 w; (E) Range light W.T. (Fresnel lens), 50 w; (F) Anchor or boom light W.T., 50w.

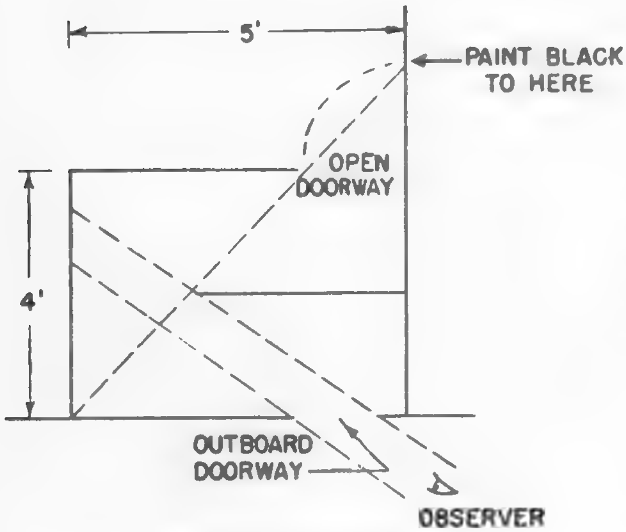


Figure 134.—Typical light trap.

—These are used to assist pilots during take-off and landing at night. They also provide visual aid to pilots for locating and identifying the parent carrier and for rendezvousing in the vicinity of the vessel.

Some of the typical types of regular permanent lighting fixtures are illustrated in figure 133.

Equipment for Darkening Ship

The term *darkened ship* designates a security condition designed to prevent any exposure of light that might reveal the location of the vessel. For assurance that interior lighting will not be visible from the outside through various accesses and openings, light traps or door switches are installed.

Light traps.—A light trap is an arrangement of screens placed inside access doors or hatches to prevent the escape of direct or reflected light from within. Inside surfaces of screens are painted flat black so they will reflect a minimum of light. The typical design of a light trap is illustrated in figure 134.

Door switches.—Owing to space limitations, it is not always possible to install light traps. For outside access doors and hatches not protected in this way, door switches are installed to extinguish lighting that would otherwise be visible from the outside. The use of door switches is generally limited to a single compartment of which the door or hatch is a part.

Door switches are mounted on the inside of compartments on the break side of the door jamp. They are operated by a stud welded to the door, so that when the door is opened, the switch is automatically opened at the same time.

Door switches are connected in various ways to suit the arrangement of compartments concerned. Where there are several doors or hatches in a single compartment, door switches are connected in series so that the opening of any one door or hatch will extinguish all lights in the compartment. When an inner compartment is located so that its light is visible from the deck when the doors to both inner and outer compartments are open, the lights in the inner compartment are usually controlled by the door switch of the outer compartment. Where this would result in an excessive number of light interruptions in the inner compartment, a separate door switch, connected in parallel with the outer-door switch, is used to control the lights of the inner compartment. With this arrangement the lights in the inner compartment will go out only when both the inner and outer doors are open.

Door-switch installations are provided with lock-in devices or short-circuiting switches to remove the door switches from lighting control when they are not required. This is done under conditions of daylight operation or when the darkened-ship condition is not required. Each standard door switch is furnished with a mechanical lock-in device used where only one door switch is required. Where two or more door switches are connected in series, a single separately mounted short-circuiting switch is installed in an accessible location to avoid the possibility of overlooking any of the door switches when a change-over is made.

Low-Level (Red Light) Illumination

The three general purposes of low-level illumination are:

1. To provide in berthing spaces standing lights that will furnish a minimum intensity of illumination sufficient to permit safe movement of personnel within the space when the regular lighting is extinguished.

2. To provide a limited number of established routes between the berthing spaces and the weather stations, with a reduced light contrast between the interior of the vessel and the dark outside deck so that the period of blindness experienced by ship's personnel going to stations on the outside deck will be reduced to a minimum.

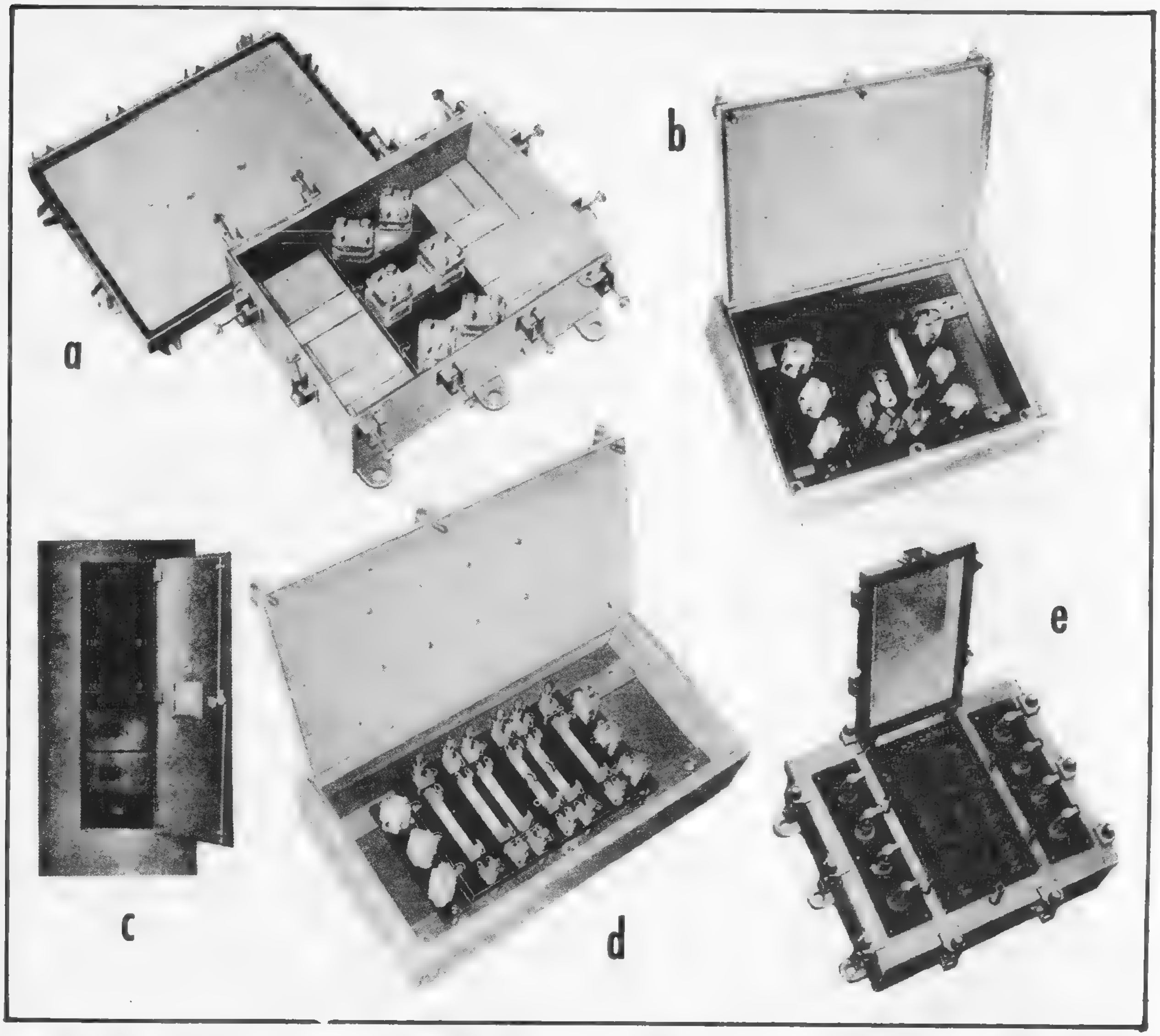


Figure 135.—Distribution boxes and panels— (a) Feeder connection box; (b) Feeder junction box; (c) Distribution lighting panel; (d) Feeder distribution box; (e) Distribution box.

3. To provide in certain compartments that open to the weather decks and in which the use of light traps or the extinguishing of lights by door switches would not be tolerable during particular circumstances of operation, an illumination which by proper arrangement of fixtures and by application of black paint and corrugations does not expose the vessel.

Red-light fixtures are connected to the local ship's service lighting circuits that feed the regular lighting fixtures in the particular compartment or vicinity. They are, however, connected to permit local control within the compartment when the regular illumination is extinguished. When red lights are installed in spaces having door-switch control of the regular lighting, the red lights are usually door-switch controlled.

Distribution Boxes and Panels

Lighting distribution requires a variety of panels and distribution boxes for interconnection of the load with the power supply. The principal items of this equipment are described below.

1. *Feeder connection box.*—Used to connect ends of feeders; it has no distribution, no switches, and no fuses. (See item *a* of figure 135.)

2. *Feeder junction box.*—Used to take off one feeder from a main feeder line; it is fused for that feeder only. (See item *b* of figure 135.)

3. *Distribution lighting panel.*—The 450-volt lighting feeders from switchboards or lighting load centers are connected to these panels through 450/117-volt transformers. Panels may be equipped with fused switches or only fuses, depending on the conditions under which they operate. Circuits emanating from distribution panels may feed distribution boxes direct, but generally they feed other distribution panels or feeder distribution boxes. (See item c of figure 135.)

4. *Feeder distribution box.*—Feeder distribution boxes differ from distribution lighting panels in size; they have only a few branch circuits in comparison with the larger panels. They may be equipped with fused switches or only fuses. Circuits emanating from feeder-distribution boxes generally supply distribution boxes. (See item *d* of figure 135.)

5. *Distribution box.*—This box is used as a means of distribution to the actual load circuits. It may be equipped with fused switches or only fuses, depending on whether or not the lights are to be controlled at the distribution box. (See item *e* of figure 135.

Searchlights

Naval searchlights are used to project a narrow beam of light for illuminating objects at a distance or for signaling. The source of light may be a carbon-arc or an incandescent lamp. In signaling searchlights, a signaling shutter or other means is used to cut off the beam of light as directed by the signalman.

Searchlight size is specified by the nominal diameter of the reflector. In general the use and principal characteristics of standard equipment are as follows:

The *36-inch searchlights* are used for navigational and fire-control purposes. A few of the older searchlights are equipped with a signaling shutter. All employ a direct-current carbon arc.

The *24-inch searchlights* are used primarily for signaling and navigational purposes. All have a direct-current carbon-arc lamp. On some models, the arc lamp can be replaced by an incandescent lamp.

The *12-inch searchlights* are used primarily for signaling and have only limited value for illumination. All use an incandescent lamp.

The *8-inch searchlights* and the signaling devices are used for signaling. All use an incandescent lamp.

Carbon-Arc Searchlights

Carbon-arc searchlights use a direct-current high-intensity electric arc between special carbon electrodes. The negative carbon consists of a soft core of carbon in a shell of hard carbon. The positive carbon has a hard core made of suitable materials surrounded by a shell of hard carbon.

The positive electrode or carbon of the high-intensity arc is aligned with the optical axis of the reflector; the negative carbon makes an angle of about 16 degrees with the axis. In operation, the core of the positive electrode is vaporized, forming a hollow crater facing the reflector and an intensely luminous ball of gas in the crater. The positive electrode is rotated continuously in order to prevent unsymmetrical burning away of the carbon around the crater and consequent spilling out of the luminous ball which is the major source of light and must be maintained at the focus of the reflector.

The nonrotating negative electrode burns away to a taper. About 3 to 5 minutes of operation are needed to form the positive crater. Both carbons are slowly consumed and must be fed gradually toward the arc.

Types of lamp mechanisms issued by the Navy differ in details of construction but all are arranged for totally automatic operation and provide for—

1. Rotation of the positive carbon about its axis to prevent the development of an unsymmetrical crater.
2. Feeding the positive carbon forward to maintain the crater at the focus of the reflector.
3. Feeding the negative carbon to maintain substantially constant voltage across or current through the arc.
4. Striking the arc.
5. Forced cooling and ventilation.

These automatic features as outlined in 1 to 2 above are accomplished by a small electric motor, the feed motor, and its associated equipment in the control box.

The positive carbon feed is controlled by a thermostat switch to maintain the light source at the reflector focus. In the arrangement illustrated in figure 136, the thermostat lens forms an image of the light source that falls the top plate of the control

box when the end of the positive carbon is at the reflector focus. The thermostat element of the switch is thus shielded from the heat of the light source. Its contacts remain open, and the positive carbon is rotated by the positive head but is not fed into the arc. When the crater has burned back approximately 0.05 inch from the focus, the crater image shifts to, and heats, the thermostat element. The contacts on the thermostat close the circuit of an electromagnet which operates the positive feed rod, preventing the rotation of a detent wheel on the positive head and causing the feed rollers to turn and feed the carbon toward the arc. When the carbon is fed forward to its proper position, the image of the light source shifts away from the thermostat, which then cools and causes the circuit of the electromagnet to be opened; this stops the forward feed of the carbon.

Arc length is controlled by feeding the negative carbon forward or back to maintain either normal arc voltage or arc current. Some searchlights are equipped with a control that holds the arc current at a normal value. The desired normal value of current or voltage is set by adjusting the tension of a spring which opposes the pull of an electromagnet in the negative feed-control circuit. With current control the electromagnet is connected in series with the arc and has an armature arranged to engage either a forward or reverse feed for moving the negative carbon closer to, or farther from, the positive carbon. When the arc current falls below the normal value, the electromagnet engages the forward feed which runs the negative carbon toward the positive until the current is restored to its normal value. The feed then stops. If the current rises above its normal value, the electromagnet engages the reverse feed and causes the negative carbon to be backed off.

Voltage control for negative electrode feed operates similarly except that the electromagnet is connected across the arc voltage and controls the feed of the negative electrode to maintain constant-

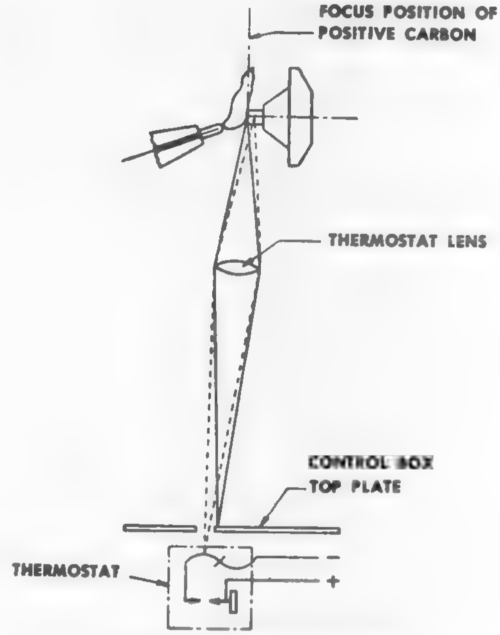


Figure 136.—Thermostat System.

arc voltage rather than constant-arc current. With voltage control the arc current depends upon the line voltage and rheostat setting and is adjusted to the value for most efficient operation by means of the rheostat. Thus in both types of control, one of the two factors that affect energy input to the arc, arc voltage, and arc current, is fixed by setting the lamp control mechanism; the other is fixed by adjusting the arc rheostat.

Typical wiring diagrams for carbon-arc searchlights are given in figure 137.

Details of various lamp mechanisms and training and elevating mechanisms are reserved to the later study of manufacturers instruction books that describe in detail a specific design of equipment.

Incandescent-lamp searchlights are electrically in very much the same category as other types of incandescent-lamp fixtures aboard ship and so do not require further consideration in this text.

Special Lighting Systems

Running, Anchor, and Signal Light Systems

Running lights are installed on naval vessels to conform with the provisions of the International Conference on Safety of Life at Sea. These provisions govern the location of each type of light, its range, and its horizontal angle of visibility. The running lights on naval vessels are similar to those used on merchant ships and include the following:

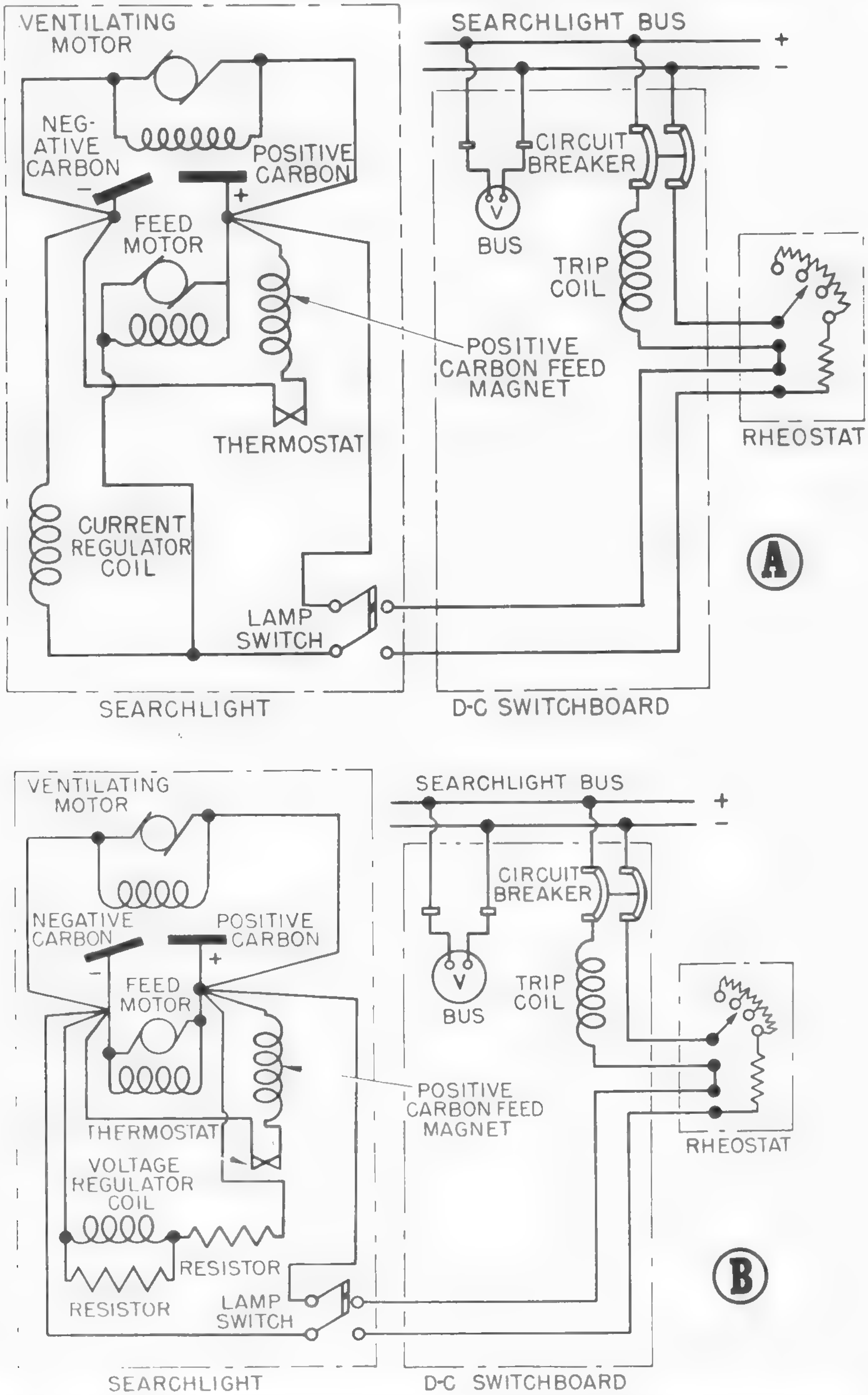


Figure 137.—Typical diagrams for carbon-arc searchlights—(A) Current-controlled lamp; (B) Voltage-controlled lamp.

Masthead light.
Starboard-side light.
Port-side light.
Range light.
Stern light, white.
Towing light, upper } not required for all vessels
Towing light, lower }

These lights are equipped with double filament lamps to reduce the hazards of failure. They are generally connected through a supply and control panel for running lights. This panel is arranged to give a visible and an audible alarm if a failure occurs in any one of the lights listed above except the towing lights. Transfer of supply to the secondary filament is made automatically in the case of failure to masthead, side lights, range light and stern light, but must be accomplished manually with manual transfer switches in the case of towing lights. The audible alarm (buzzer or bell) may be cut off by a switch on the panel but the visible alarm (red light) remains on until the lamp in the running-light fixture is replaced. The appearance of a standard supply and control panel for running lights is shown in figure 138.

Combat ships use a variety of anchor and signal lights, depending on the function of the particular vessel. Anchor and signal lights common to practically all ships are as follows:

Anchor light, forward.
Anchor light, aft.
Speed lights.
Blinker lights.
Wake light.
Steering light.
Aircraft warning lights.
Man-overboard and breakdown lights.

The lamps of all lights listed above are single filament with the exception of the wake light. This light is connected through the supply and control panel with the same arrangement of alarm and automatic change-over as outlined for certain running lights.

Speed lights are provided to indicate the speed of a vessel to other ships in formation. Two speed lights are generally installed on the mainmast and used under normal conditions. A single speed light installed at the stern of the vessel is used under darkened-ship conditions.

The speed indication to other ships is given by a pulsating light from either the truck lights or the stern speed light. The rate of pulsation is governed by the setting on a speed controller that operates in conjunction with a motor-operated pulsator to provide the required signal.

The speed-light pulsator rotates at constant speed for all settings of the speed-light controller. The pulsating signal is produced by stationary fingers riding on discs which are arranged to alternately open and close a circuit to develop certain timed signals. The change from one signal to another is controlled by the manually operated speed controller which selects the particular finger and disc for the signal required.

Speed controllers have dials with speed markings for the various positions of the operating handle. A typical controller is marked as listed below:

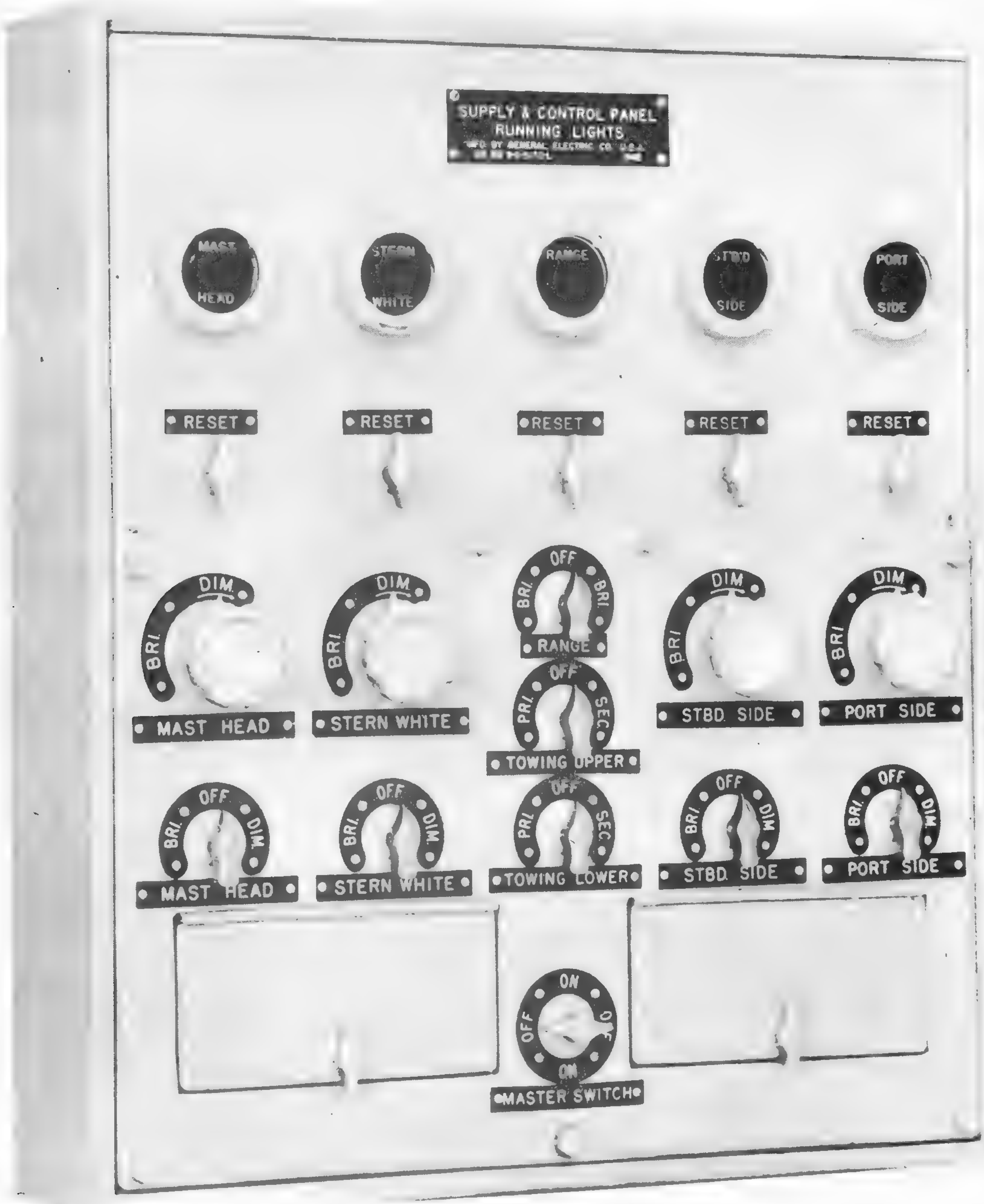
Markings	*Pulsations*
Standard speed ahead	Steady white.
One-third speed ahead	1 white flash in 6 seconds.
Two-thirds speed ahead	2 white flashes in 6 seconds.
Full speed ahead	4 white flashes in 6 seconds.
Flank speed ahead	5 white flashes in 6 seconds.
Stop	Steady red.
Slow speed back	1 red flash in 6 seconds.
Full speed back	2 red flashes in 6 seconds.

Speed lights are equipped with a white lens for indicating "ahead" speeds and a red lens for indicating "stop" and "back" speeds. Each lens is lighted by separate lamps on separate circuits. The speed controller makes the selection between these circuits for connection to the pulsator, depending on whether the ship is proceeding ahead, astern, or is stopped.

Blinker lights are used for transmitting messages from one ship to another or from ship to shore. A blinker set generally consists of two lights mounted on the port and starboard sides of a yardarm and two blinker keys located on the port and starboard sides of the signal bridge.

The wake light is installed on the flagstaff or the after superstructure in such a position as to illuminate the wake of the vessel and so that no part of the vessel's structure is illuminated. The reflected light from the wake of the vessel is used when proceeding in formation to indicate its relative position with respect to ships which are astern of it.

The steering light consists of a cylindrical metal casting enclosing a low candlepower lamp and has a small opening to emit light. It is installed on a forward jackstaff so as to be visible to the helmsman.



Courtesy of General Electric Co.

Figure 138.—Supply and control panel for running lights.

Aircraft warning lights consist of a cluster of six small lamps installed at the trunk of each mast that extends 5 feet or more above the highest point of the superstructure. These lights are used as obstruction lights to indicate trunks of masts to low-flying aircraft. They are displayed only when at anchor in areas where air activity warrants their use.

Man-overboard and breakdown lights consist of two-360-degree red fresnel lens lights, mounted in a vertical line, one over the other, not less than 6 feet apart at the same hieght as the masthead light. These lights indicate to other vessels that the vessel showing them is not under command and cannot therefore get out of the way.

Flight-Deck Lighting for Aircraft Carriers

The following lights constitute the lighting of the flight deck:

Signal and homing lights.
Identification lights.
Bow-designation lights.
Signal light bars.
Turning light.
Deck-edge lights.
Deck surface lights.
Guide lights.
Ultra-violet flood lights for landing signal officer.
Landing-signal wands.

Arrangement of Hangar-Deck Lighting for Ship-Darkening

The hangar deck on an aircraft carrier has a great variety of doors, roller metal curtains, elevators, and other accesses to the outside, which must be guarded with door switches for protection against light exposure. Since it is such a large space involving many door switches, the hangar deck under darkened-ship conditions is sectionalized into smaller areas, with each area controlled by its respective door switches. Two athwartship canvas curtains are used to divide the hangar deck into three bays of approximately equal size. These light-tight curtains allow any one of the three bays to be used for handling or repairing planes while the elevators or doors are open in the other bays.

Two sets of curtain-operated switches are located at each of the light-tight canvas curtains for the purpose of making each bay independent of the others while the curtains are closed but for combining the control of the bays when the curtains are open. The curtain-operated switches operate with door switches and relay-controlled contactors to set up the following conditions:

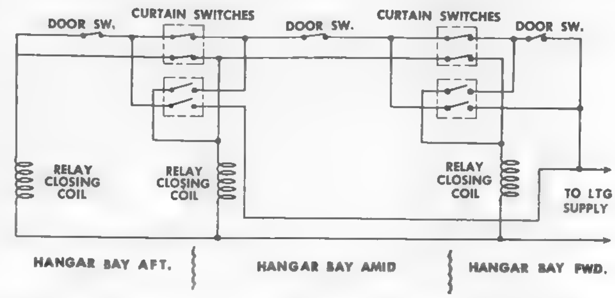


Figure 139.—Schematic diagram of hangar lighting control (curtain switches shown in position for open curtains).

1. *Both curtains closed*: The opening of any door switch will extinguish the lights only in that bay of which it is a part.
2. *Forward curtain open, after curtain closed*: The forward and middle bay operate as a unit with a door-switch opening in either bay, extinguishing the lights in both bays. The after bay is an independent unit and is only controlled by its associated door switches.
3. *Both curtains open*: All three bays become a single unit so that the opening of any door switch will extinguish the lights in the entire hangar space.

Red-globe deck fixtures that are a part of the low-level illumination system are not connected into the hangar-deck control system and, therefore, remain energized under all conditions cited above.

Through manually operated swiches located in each bay of the hangar space, provision is made for cutting out the automatic control system as described above. These switches have three positions, marked "Off," "Automatic," and "Manual."

Figure 139 is a schematic diagram of the hangar-deck control system. Note in referring to this diagram that when a circuit is completed to a relay-closing coil, the lighting of that particular bay is on, since in the actual control the relay closes a contactor in the lighting-supply circuit.

Direct-Current Lighting Systems

Direct-current lighting systems on auxiliary ships follow the same general scheme of distribution as described for a-c systems. With the exception of

some of the smaller ships, the power supply at the generators is 3-wire, 240/120 volts, with positive, negative, and neutral leads from the switchboard buses being brought out as main lighting feeders to the principal lighting distribution panels. Final distribution from the distribution boxes to branch-load circuits is 2-wire, 120 volts, and the load is approximately balanced on the 3-wire system by the connections of branch circuits inside of distribution boxes.

Maintenance

Cleaning Schedule

Maintenance of the greater portion of a lighting system is primarily a matter of cleaning the fixtures and lamps periodically, making lamp replacements as required, and repairing portable appliances. There are, however, special systems employing control parts subject to misadjustments, burn-outs, and the like. This equipment must be serviced with the same detailed procedures as outlined for comparable devices in previous chapters on switchboards, power distribution, and motor control.

Light depreciation caused by the accumulation of dirt on lamps and fixtures results in serious impairment to the efficiency of a lighting system. Most of this loss is preventable. The actual loss of light from this cause depends on the extent to which oil fumes, soot, and dust are present in the atmosphere and on the frequency with which fixtures are cleaned.

Schedules for cleaning lighting fixtures should be developed to fit the conditions and requirements aboard individual vessels. Fixtures and lamps should be examined at frequent intervals and cleaned when the first sign of dirt, soot, oil film, or salt incrustation is detected.

Lamp Replacement

Considerable effort should be expended to replace lamps which, by their blackened appearance, indicate they are subject to an early failure. A general survey of all lamps should be conducted periodically to make these replacements in order to avoid the inconveniences that otherwise result when actual faiiure occurs. Obviously, good judgment should be exercised in determining when an old lamp needs replacement in order to guard against unnecessary waste.

An examination of burned-out lamps will familiarize personnel with the degree of blackening attained by such lamps and will help determine the lamps in service that should be replaced.

Fluorescent Lights

Failure of fluorescent lights can usually be attributed to worn out or defective starters or to damaged or expended lamps. Thus, when a fluorescent light shows defective operation, the difficulty can usually be remedied by replacing either the starter or the lamp or both. Where fluorescent lamp tubes are equipped with a lock to prevent their dislodgement under shock, care should be taken when renewing lamps to transfer the lock from the old to the new lamp.

Hand Lanterns

Hand lanterns operate from dry cells; and since they are energized infrequently, the batteries must be checked periodically. This should be done at least once every 3 months by connecting a 1.7-ohm resistor across the terminals of each dry cell and reading the cell voltage at the end of 1 minute. Under these conditions any cell giving a reading of less than 1.20 volts should be discarded and replaced with a fresh cell. Lanterns in boiler and engine rooms are sometimes subjected to temperatures consistently higher than 90° F. In such locations, a check should be made once each week.

With the automatic-type lanterns the relay should be tested each week for assurance that it is in good operating condition. This operation can be checked by de-energizing the particular lighting circuit to which it is connected and observing whether or not the lantern light is on.

CHAPTER 11

ELECTRIC CABLE

Cable Classification and Types

Adequate-Cable Installation

The reliability of a ship's distribution system is to a large extent characterized by the adequacy of its cable installation. This adequacy is not only concerned with current-carrying capacity and insulation strength, but it is also related to the ability to withstand the varied conditions of service exposure, including heat, cold, dryness, bending, crushing, vibration, twisting, and shock.

It is not to be expected that any one class of cable can be designed to meet the extreme variations in the degree of service exposure imposed by the electrical installation aboard a combat ship. Experience and tests have proved that all conditions can be satisfied only by making available a wide variety of different designs to suit the numerous applications.

The rating and characteristics of the various classes of Navy shipboard cable are presented in table form in General Specification S62–2. These tables are supplemented with descriptive matter relative to application and approved methods of installation so that the specification in its entirety serves as a guide in the development of electrical plans and actual installation aboard ship.

Installation of cable by a ship's crew is generally limited to minor alternations of lighting and interior-communication circuits. The engineer officer at sea is, therefore, little concerned with problems related to the choice of cable or its installation. When a ship is in a naval or private shipyard undergoing major alternations or repairs, changes or additions to the cable installation may be made. Under these conditions it is desirable that an engineering officer be familiar with the principal classes of cable and their application as an aid toward processing work orders with naval engineers stationed in the yard. The discussion of cable installation in this text is limited in scope to this consideration.

Heat- and Flame-Resistant Cables

Heat- and flame-resistant cables with protective armor constitute about 98 percent of the permanently installed distribution wiring for lighting, power, communication, and fire control. These cables employ synthetic resin or varnished cambric as primary insulation, supplemented by asbestos for heat and flame resistance and a braided protective armor. They are distinguished by the letter designation "HFA" and include the following types:

SHFA------Single conductor.
DHFA------Twin conductor.
THFA------Three conductor.
FHFA------Four conductor.
MHFA------Multiconductor.
TTHFWA---Twisted pair, telephone.

Multiconductor cables are available up to 44 conductors, with each conductor having a cross-sectional area of 2,828 circular mils. These cables are used almost entirely for interior-communication permanent wiring where flexing service is not required.

Twisted-pair telephone cables are available up to 60 pairs of conductors with each conductor having a cross-sectional area of 703 circular mils. These cables are principally used for automatic telephone systems, but there is a limited application for them at centralized distribution parts of sound-powered telephone systems.

SHFA-, DHFA-, THFA-, and FHFA-type cables are associated primarily with the power and lighting system, although there is some application in the

smaller sizes for interior-communication systems where these numbers of conductors are all that are required. SHFA-type cables are available up to 829,300 circular mils in conductor cross section, whereas the maximum for DHFA-, and THFA-type cables is 413,600 circular mils. FHFA-type cables have a limited application in low-capacity circuits and are available in two sizes: 2,828 circular mils and 4,497 circular mils.

Other types of heat- and flame-resistant cables suitable for permanent installation include:

SHFS----Switchboard—single-stranded conductor—953 to 99,060 circular mils.

SHFW---Switchboard—single-solid conductor—1,022 to 20,820 circular mils.

SHFR----Radio — single-stranded conductor—4,497 circular mils.

DHFR---Radio—double-stranded conductor—4,497 circular mils.

THFR---Radio — triple-stranded conductor—4,497 circular mils.

SHFL----Submarine propulsion—single-stranded conductor—leaded 413,600 to 1,046,000 circular mils.

HFS- and HFW-type cables are utilized within the limitations of their respective ratings for all portions of switchboards, panels, and similar equipment.

HFL-type cables are utilized for main propulsion circuits of submarines and on surface ships where the service conditions are unusually severe and the installation is subject to highly varied conditions with respect to ambient temperatures, moisture, and oil.

Radio cables of the HFR class are applied to high-voltage radio installations where the voltage does not exceed 3,000 volts.

Cables for Repeated Flexing Service

There are many applications aboard ships of the Navy which require cables that can be subjected to repeated bending and twisting without injury to conductor, insulation, or protective covering. This class of cable is generally employed with portable equipment, but it has some degree of permanency of installation when used to connect circuits in rotating structures to the distribution wiring of the ship. This applies to lighting, power and interior-communication circuits in center columns, directors, boat cranes, and gun mounts, where sections of flexible cable are connected between connection boxes mounted in the rotating structure and those mounted in the fixed structure.

Leads to portable equipment, such as submersible pumps, blowers, heaters, electric tools, and telephone headsets, are all of flexible cable construction. Ship-to-shore connections and casualty power jumpers are also in this classification.

Flexible cables employ synthetic rubber or synthetic resin insulation and an impervious sheath which is resistant to water, oil, heat, and flame. Distinguished by "OP" or "FF" in the type letter designation, they are heat and flame resistant to a somewhat lesser degree than armored "HF" or "HFA" cables.

The following types of cable are for connection to portable electric appliances, or permanently installed appliances, where the leads are likely to be subjected to repeated bending and twisting of a very severe nature and where the maximum resistance to oil and mechanical abrasion are primary considerations:

SCOP-----Single conductor—22,910 to 812,700 circular mils.

DCOP----Double conductor—525 to 671,000 circular mils.

TCOP-----Three conductor—525 to 413,500 circular mils.

FCOP-----Four conductor—2,613 to 183,100 circular mils.

MCOP----Multiple conductor up to 44—2,613 circular mils.

TTOP-----Telephone twisted pair up to 60 pair —953 circular mils.

MCOS----Multiple conductor shielded up to 7—825 to 1,640 circular mils.

In addition to the foregoing the following types of cable are for similar applications, where the maximum resistance to heat and flame and mechanical abrasion are the primary considerations.

MHFF----Multiple conductor up to 44—2,613 circular mils.

TTHFF---Telephone twisted pair up to 60 pair —953 circular mils.

Designation of Conductor Size for Lighting and Power Cable

Conductor sizes for lighting and power distribution cable are designated by numbers which are to the nearest even thousand of the actual circular mil area. These numbers follow the type and class designation; for example, DHFA-3 indicates a double-conductor heat- and flame-resistant cable with armor and 2,828-circular mil conductors.

Switchboard and panel-wiring cable designations follow this system for most sizes, except in some of the smaller sizes where the number is carried out to the nearest 500; for example, SHFS-2 ½ indicates a conductor of 2,613 circular mils.

Designation—Number of Conductors

Multiple conductor and telephone cable type and class designations are followed by a number which indicates the number of conductors for a multiple conductor cable and the number of twisted pairs for a telephone cable. Thus, for example, MHFA-30 is a multiple conductor, heat and flame resistant, armored cable with 30 conductors, and TTHFWA-25 is telephone, heat and flame resistant, armored cable with 25 twisted pairs.

Appearance

In viewing cable permanently installed in wireways aboard ship, there is no difference in the appearance of one cable from another, except perhaps a difference in the outside diameters. Two cables of almost equal diameters may, however, be radically different in the character of their application, as would be the case with a DHFA-50, which has an outside diameter of 1.220 inches, and a MHFA-19, which has an outside diameter of 1.210 inches.

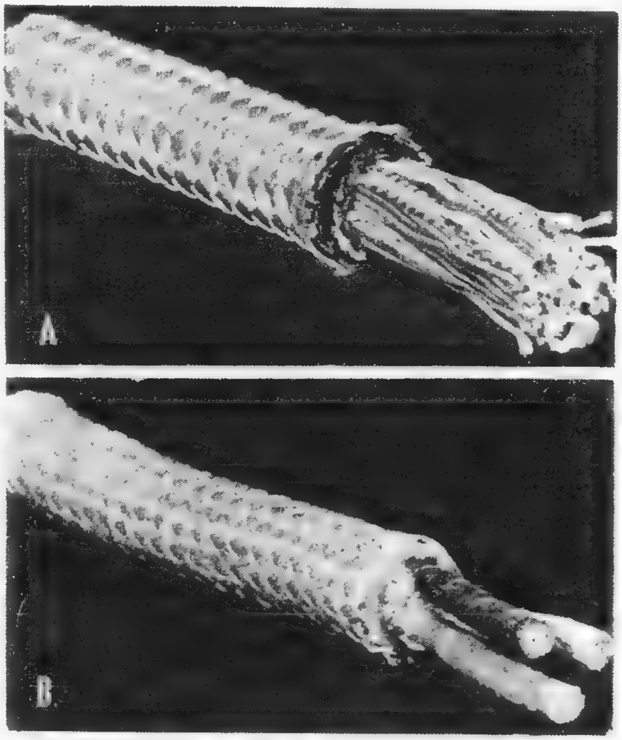
When two different cables are cut and the internal conductors and insulation exposed, the class and application becomes more evident, as illustrated in figure 140.

Selection of Lighting and Power-Cable

The size of cable selected for power and lighting circuits depends on three factors: the current requirements of loads connected to the cable, the permissible voltage drops in the cable, and the ability of the cable to carry current without excessive rise of temperature.

Current-carrying capacity rather than voltage drop is, in almost all cases, the determining factor in the choice of cable sizes to fit particular load requirements. This capacity is dependent not only on the size and type of conductor but also on the permissible rise of temperature, the grouping of cables in wire racks, ambient temperature, and the character of the space in which the cable is installed.

Cable size is generally selected on the basis of the maximum continuous current-carrying capacity, as listed for all classes and sizes in specification S62-2. These ratings are given for ambients of both 40° and 50° C. and are applicable for practically all installation conditions. Locations or cable groupings that restrict the normal rate of heat flow are given special consideration in specifications by limiting the maximum load to 85 percent of the listed cable rating. Occasions for this procedure are few and do not require discussion for purposes of this text.



Courtesy of Cornell Maritime Press.

Figure 140.—Typical shipboard cables—(A) TTHFWA; (B) THFA.

Cable Installation

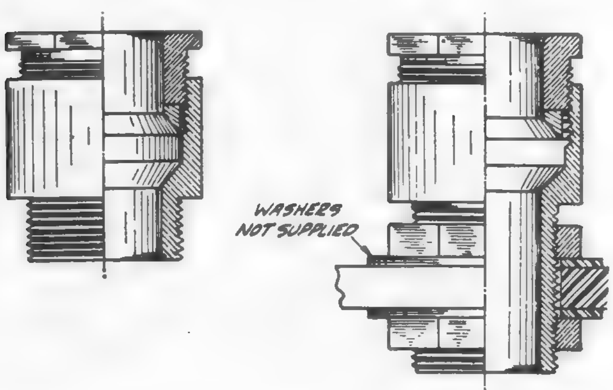
Since it is assumed that no major cable installation is to be undertaken by a ship's crew and that the engineer officer's part in the processing of work orders to a naval or private shipyard is not concerned with the techniques or intricacies of the work itself, only the more basic considerations of shipboard wiring are outlined here. It should be pointed out, however, that cable installation on new construction, repairs, and alterations, follows definite rules and regulations as set forth in the Bureau of Ships Specifications and is not entirely a matter of judgment on the part of a ship's crew or the yard that is performing the job.

Basic Installation Data

1. *Cable connections.* All connections to cables, change in any cable run from one type of cable to another type, all changes in conductor size other than at switchboards or panels, and at normal breaks in a cable should be made in standard appliances and fittings. No splice connections are permitted in an electric plant installation.

2. *Cables entering watertight appliances.* Wherever cable enters a watertight appliance, a Navy standard terminal tube should be used.

3. *Cables entering nonwatertight appliances.* Sheet-steel enclosures bulkhead mounted—terminal tubes. Sheet-steel enclosures overhead mounted—terminal tubes or cable clamps. Cast-metal enclosures up to 3/16 inch thick—cable clamps. Cast-metal enclosure over 3/16 inch thick—terminal tubes. Molded-phenolic enclosures—entrance through closely fitted drilled holes.



Courtesy of Cornell Maritime Press.

Figure 141.—Typical terminal tube installation with locknut fastening.

4. *Cables through watertight bulkheads and decks.* Where cables pass through decks and watertight bulkheads, watertight stuffing tubes should be used.

5. *Cables through nonwatertight bulkheads.* Where cables pass through nonwatertight bulkheads or beams which are 1/4 inch or more in thickness, no stuffing tubes should be used, but the holes therein shall be drilled slightly larger than the cable and the holes rounded off to prevent chafing of the leads. Where the nonwatertight bulkheads or beams are less than 1/4 inch in thickness, bushings should be used.

6. *Protection of cables passing through decks.* All cables passing through decks should be protected from mechanical injury by means of kick pipes or riser boxes.

In general kick pipes (conduit) should consist of a length of steel pipe attached to the deck usually by welding and should have a stuffing tube threaded to the upper end. Where installation is made in nonwatertight decks, a conduit bushing may be substituted for the stuffing tube. Kick pipes should be 9 inches in height, including the stuffing-tube body, except where longer lengths are required for proper cable protection.

Where three or more leads pass through a deck in a single group, individual kick pipes may be omitted and a steel box (riser box) 9 inches in height substituted.

7. *Cable bends.* Cables should not be subjected to bends of smaller radii than shown in the tables of specification S62–2. Where practicable, all bends should be made over a mandrel, to assure freedom from sharp kinks.

NOTE.—Excessive bending will damage cable to the extent that it will lose its heat-, flame-, and water-resistant properties and eventually result in a breakdown in that part of the electrical system.

Terminal Stuffing Tubes

Terminal tubes are used to make watertight connections between cables and electrical appliances and fittings. Generally they consist of three principal parts: the *gland nut, gland ring,* and *tube body.* The tube body is fastened to the box, and the gland nut and ring are used to compress the packing around the cable as shown in figure 141.

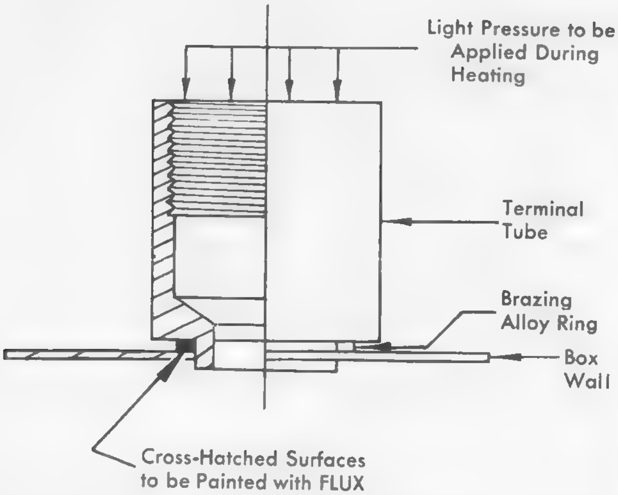


Figure 142.—Typical terminal tube installation with brazed fastening.

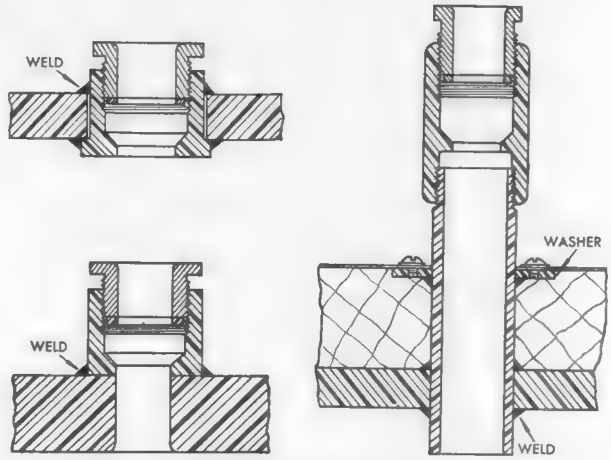


Figure 143.—Typical installations of stuffing tubes.

The majority of terminal-tube installations are similar to that shown in figure 141, which has a locknut on the inside to secure the tube body to the enclosure. There are a few examples, however, where the tube is brazed to the enclosure wall in the manner shown in figure 142.

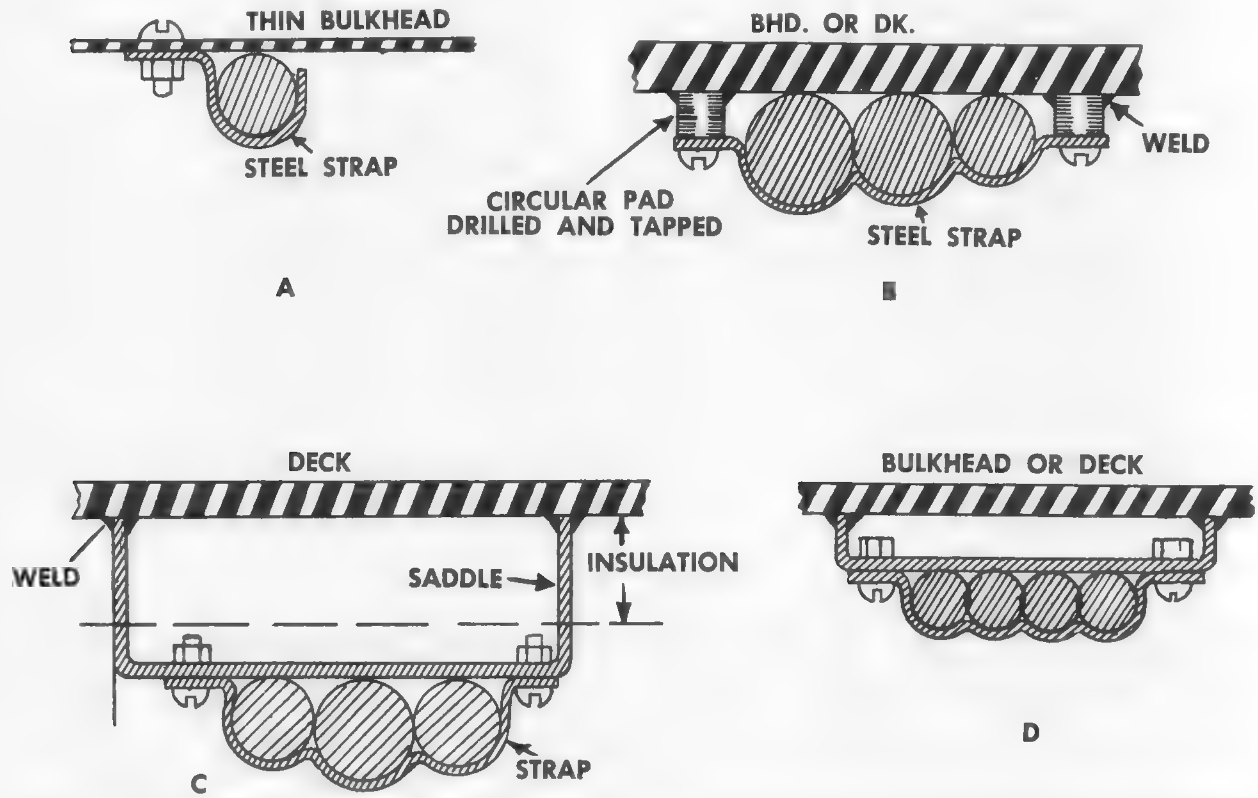


Figure 144.—Typical methods of supporting small cable installations—(A) Single cable on thin bulkhead; (B) Three cables with welded pads; (C) Three cables with saddle (insulated deck); (D) Hanger installation on decks and bulkheads subject to dampness.

Stuffing tubes are used for passing cables through watertight decks and bulkheads. They differ from terminal tubes only in the tube-body construction. Tube bodies are available in several types, and these are applied in various ways, as illustrated by the typical installations in figure 143.

SUPPORTING CABLE ON DECKS AND BULKHEADS

The methods for supporting cable depend on the number and size of cables in the particular run, thickness of bulkhead or deck, ship's structure in way of cables, and whether or not the bulkhead or deck is insulated. In consideration of the number and size of cables in concentrated power areas, such as switchboard locations, the cable supports must necessarily be in the form of racks, representing a sizeable amount of fabrication of flat bars, angles, and cable straps. For purposes of supporting a few of the smaller sizes of cables for small alterations in power-lighting and interior-communication circuits, the methods illustrated in figure 144 will generally suffice.

Cable Maintenance

Measuring Insulation Resistance

The major part of cable maintenance is devoted to checking and recording the insulation resistance of the various circuits. These measurements are concerned primarily with the permanently installed cable on the ship, mostly of the HFA type. Measurements are made with a megger by making contact with the two leads to conductor and cable armor, respectively.

The primary purpose of making insulation resistance measurements of shipboard cable installations is to determine the condition of the cable in order that deterioration and incipient failure may be discovered and remedied. In taking these measurements, it is necessary to take into consideration four factors that will affect the insulation and to evaluate the results accordingly. These factors are as follows:

1. Other apparatus connected in the circuit.
2. Total quantity (number and length) of cable measured.
3. Type of cable.
4. Temperature of cable when measured.

In taking measurements, it may be convenient to leave certain other apparatus, such as switches, circuit breakers, and connection boxes, in the circuit. If such measurements indicate resistances which are satisfactory when compared to previous values or limiting values, no further isolation of the cables may be necessary; but if the resistances are low in comparison with the desired standard, it will be necessary to disconnect the cable completely and measure it alone before concluding that the cable is responsible for the condition. In all cases it is important to record the other apparatus in the circuit as a basis of comparison with subsequent readings or past readings.

The insulation resistance of a cable varies inversely as its length, since the total resistance is the resultant of a number of small individual leakage paths or resistors distributed along the cable and connected between the conductor and the cable sheath. Thus, in order to have a common unit of comparison, cable insulation resistance should be expressed in megohms per foot of length.

The condition of a cable as determined by its insulation resistance can be judged only by considering its type and temperature. Since there is some variance in insulation temperature characteristics in relation to the type of cable measured, characteristic curves are of material value as a basis for comparison. HFA type cables are the most common type aboard ship, and the curves of figure 145 are therefore confined to illustrating their characteristics.

Fairly accurate temperature measurements on the sheath of a cable must be made to permit a reliable interpretation of the insulation-resistance measurements.

All ships keep a record of insulation measurements made on the various circuits. By comparison of each set of readings taken with previous readings, a fairly accurate gage of insulation strength can be obtained. Conditions that may be causing sharp decreases in the insulation resistance of a cable are generally indicated in these comparisons.

The causes of low insulation resistance are as follows:

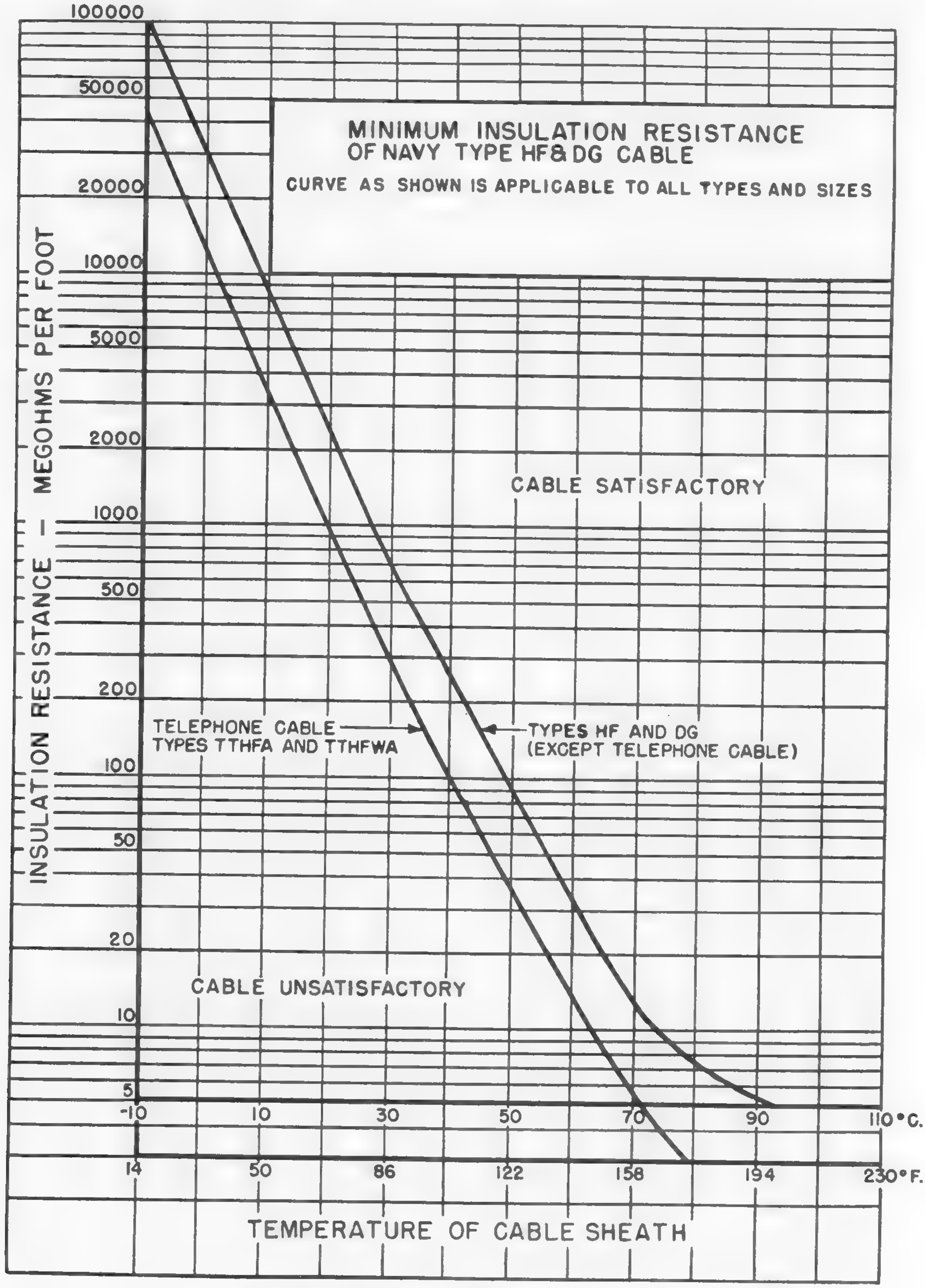


Figure 145.—Temperature insulation-resistance curves.

1. Low resistance paths between conductor or conductor lug at the cable ends. Armor should be cut back at least 1 inch from the point where the impervious sheath is cut. Impervious sheath at cable ends should be cleaned of paint applied in the process of manufacture, since such paint acts as a conductor.

2. Cable ends are sealed against entrance of moisture in approved methods of installation; but under long periods where a cable may not be carrying current, moisture may get in. If excessive moisture in a cable is suspected, special treatment to drive it out may be warranted. The sealing means at the cable ends may be removed and the cable heated by passing current through the conductor, starting with a low current and gradually raising it until a cable sheath temperature of not more than 180° F. is attained. Care should be taken not to heat the cable too rapidly. The whole drying operation may require several days. A welding generator, low-voltage degaussing generator, or other auxiliary generator that can be isolated for the purpose and whose output voltage can be suitably controlled may be used for supplying this heating current. Cables should be resealed immediately after the heating current is removed in order to prevent moisture from the air being drawn back into it. The resealing should take place while the cable is still hot.

3. When low insulation resistance of a cable is caused by physical damage or by immersion in water, replacement of the cable is generally required to effect permanent repair. The method of drying out described above is only applicable to cables which have absorbed moisture from the air and should not be attempted where salt water has entered as a result of submergence.

Painting

The braided armor of permanently installed cable is made up of many strands of fine steel or aluminum wire. This wire is subject to rapid corrosion on exposed decks if not protected with zinc chromate paint. The usual process is to touch up bare surfaces with zinc chromate and them to apply a finish coat of the same color as the ship's structure in that area. While the chief concern is to cables exposed to weather, the same procedure should be applied to cables below deck where bare surfaces are discovered.

Ground Connections

The armor of all cables within radio spaces or otherwise exposed to radio-frequency fields is grounded to the ship's structure closely adjacent to to fixture or appliances to which they are connected and also at several points along the cable length, usually at alternate cable hangers. This grounding is accomplished by a securing clamp fastened around the cable armor and connection of this clamp to the ship's structure with a strip of sheet steel, which is in turn connected to a suitable pad on the ship's structure with machine screws. It is important that in the process of maintaining electrical equipment that these ground connections be given an occasional check and tightened as necessary to assure a good connection.

Terminal Tubes and Stuffing Tubes

Gland nuts of terminal tubes and stuffing tubes occasionally work loose because of vibration on a ship. As a result the effectiveness of the packing in assuring a watertight entrance of a cable is lost. Considering the number of such tubes on a ship, it is not practical to conduct a survey over the entire ship at regular intervals. But in the course of carrying out other maintenance work tubes should be examined. Particular attention should be given to stuffing tubes installed in watertight decks and bulkheads. Owing to the construction of stuffing tubes, depression or "necking" of the cable may be caused by successive tightening of gland nuts and if carried to excess may ultimately damage the cable.

CHAPTER 12

ELECTRIC PROPULSION (SURFACE SHIPS)

Development of Propulsion Machinery

Before the development of steam turbines and Diesel engines as ship's propulsion machinery, ships were propelled by relatively slow-speed steam reciprocating engines. Efficient speeds of these engines coincided with efficient speeds for propellers so that propeller shafts could be coupled directly to engine shafts. Furthermore, the steam reciprocating engine was very adaptable for rapid reversing and the speed changes required for maneuvering.

For reasons of operating economy and savings in weight and space, the steam reciprocating engine has become obsolete as a propulsion unit and has been completely replaced by steam turbines or Diesel engines on ships of modern design. The rotational speeds of most Diesel engines used for propulsion are relatively high, and of steam turbines still higher. Propellers, on the other hand, must turn at relatively low speeds for efficient operation. Some means of speed reduction between the driving machine and the propeller shaft is required in order to realize the best over-all efficiency. This has been accomplished by two general methods: reduction gears and electric propulsion.

In the first method, turbine or Diesel-engine power is transmitted mechanically through a train of gears directly to the propeller shaft. In the second method, the turbines or Diesel engines drive electric generators that electrically transmit this power to motors driving the propeller shafts. A certain amount of speed reduction through gears is sometimes required between the prime mover and generator and between the motor and propeller shaft.

In the era of transition between the slow-speed steam reciprocating engine and high-speed steam turbines for ship propulsion, large reduction gears had not been sufficiently developed to provide reliable service on naval capital ships. Electric propulsion, on the other hand, had successfully proved itself on the first electrically propelled naval surface ship, the collier *Jupiter*, which was later converted to the aircraft carrier *Langley*. The favorable service record of this vessel strongly influenced the application of a-c turbo-electric propulsion on two aircraft carriers and seven battleships completed shortly after World War I.

Soon after the completion of these vessels, turbine-geared drive came into extensive use on merchant and passenger vessels and proved itself highly successful. While electric drive permitted greater flexibility in arrangement of machinery and proved more economical at cruising speeds, the greater savings of weight and space with reduction gears outweighed these advantages in large surface ships. Thus, when construction of capital ships was resumed after 1930, the use of reduction gears for propulsion plants in the higher ranges of power capacity had been standardized by the Navy and no further installations of electric propulsion were made on capital ships.

This standardization of turbine reduction-gear drive for large combat ships did not, however, eliminate electric propulsion from consideration on vessels requiring propulsion plants of medium or small capacities. The Navy has continued to install electric propulsion on certain types of surface vessels for the following reasons:

1. Direct-current electric propulsion provides exceptional operating flexibility at reduced speeds and under towing conditions; thus it is highly desirable for tugs, ice breakers, salvage ships, and net-laying ships.

2. Propulsion generators of an electrically propelled vessel may be used to provide power for large pumps, cargo-handling gear, and other purposes. They have been used to advantage on tugs equipped with large motor-driven fire pumps, tankers equipped with large cargo pumps, and mine sweepers with magnetic sweeps.

3. In the last war, the availability of reduction gears for propulsion became critical. Since electric propulsion could serve the same purpose of reducing speeds between the propulsion engines and the propeller shafts and could be procured more readily than reduction gears, it was widely used on several classes of vessels, particularly on escort vessels (DE).

4. Electric propulsion permits maximum flexibility in the number, size, speed, and type of prime movers. This feature was of special importance during the last war when the choice of Diesel engines was limited to those most readily available. Electric propulsion not only provided the necessary speed reduction but permitted shipboard machinery arrangements best adapted to the types of vessels involved.

TYPES AND APPLICATION OF ELECTRIC PROPULSION

There are three types of electric drive in use aboard naval vessels today: Diesel d-c drive, Diesel a-c drive, and turbine a-c drive. Adaptibility of these types to various horsepower requirements and their application to naval surface vessels are discussed below:

1. *Diesel d-c drive* is best suited to vessels in the low or medium horsepower range up to about 6,000 shaft horsepower. It has been installed in approximately 175 escort vessels and 500 surface vessels of other types, including mine sweepers, submarine tenders, fleet and harbor tugs, fuel-oil tankers and barges, rescue and salvage vessels, net-laying ships, freighters, coast guard vessels, ferries, and miscellaneous unclassified vessels.

2. *Diesel a-c drive* is best adapted to medium horsepower installations ranging from about 4,000 to 12,000 shaft horsepower. Its application so far has been limited to the submarine tender USS *Sperry*, a 10,000-ton, twin-screw vessel with 11,800 shaft horsepower. Diesel a-c drive is not considered further in this text inasmuch as the *Sperry* is the only commissioned vessel today with this type of propulsion.

3. *Turbine a-c drive* is best suited to installations of about 6,000 shaft horsepower or more. Approximately 350 naval vessels have been equipped with a-c turbine electric drive. These include escort vessels (DE), cargo and troop transports (AP, APD, APA, AKA), and oilers (AO).

Fundamentals of Ship Propulsion

Variation of hull resistance at moderate speeds of any well-designed vessel is approximately proportional to the square of the speed. The power required to propel a ship is proportional to the product of the hull resistance and speed. It therefore follows that under steady running conditions the power required to drive a ship is approximately proportional to the cube of the ship or propeller speed. While this relationship is not exact enough for actual design, it does serve as a useful guide for operating the propelling plant.

Since the power required to drive a ship is approximately proportional to the cube of the speed of the ship, 50 percent of full power will drive a ship at about 79.4 percent of the maximum speed attainable when full power is used for propulsion, and only 12.5 percent of full power is needed for about 50 percent of maximum speed. Many types of electric drive provide several generators which are all used when full power is needed, but one or more generators can be shut down when cruising at reduced speeds.

The relation of speed, torque, and horsepower to ship's resistance and propeller speed under steady running conditions can be expressed in the following equations:

$$S = k_1 \text{ x (rpm)}$$
$$T = k_2 \text{ x (rpm)}^2$$
$$\text{shp} = \frac{2\pi k_2}{33{,}000} \text{ x (rpm)}^3$$

where S = ship's speed in knots
T = torque required to turn propeller in pound feet
shp = shaft horsepower required
rpm = propeller revolutions per minute
k_1, k_2 = proportionality factors

The proportionality factors depend on many conditions such as displacement, trim, condition of hull and propeller with respect to fouling, depth of

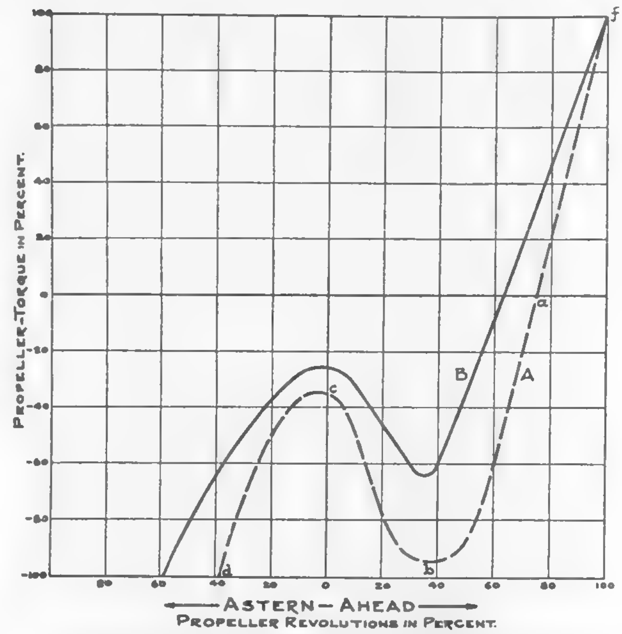
water, sea and wind conditions, and the position of the ship, whether she is going ahead or astern. Conditions that increase the resistance of the ship to motion cause k_1 to be smaller (zero in the limiting case when the ship is tied so securely that motion is entirely prevented) and cause k_2 to be larger.

In a smooth sea, the proportionality factors, k_1 and k_2, can be considered as being reasonably constant. In rough seas, however, a ship is subject to varying degrees of immersion and impact of waves which cause these factors to fluctuate over a considerable range. It is to be expected, therefore, that peak loads, that may be in excess of the load required in smooth sea, will be imposed on the propulsion plant, to maintain the vessels rated speed. Thus, propulsion plants are designed with sufficient reserve torque and power to handle the fluctuating loads which are applied in this way.

There is no simple relation for determining the torque or power required to reverse the propeller when the ship is moving ahead, or the torque required to turn the propeller ahead when the ship is moving astern. To meet Navy requirements, a ship must be able to reverse from full-speed ahead to full-speed astern within a prescribed period of time Consequently, the propulsion plant of a particular ship must be designed to furnish sufficient torque to meet reversing specifications.

Torque requirements for ship-reversing operations are determined from model tests of self-propelled models, usually performed at the Daivd Taylor Model Basin, Washington, D. C. From these tests a family of curves is plotted, one curve to show the torque required to turn the propeller at different speeds ahead and astern when the ship is moving through the water at full-speed ahead, and many other similar curves for lower ship speeds.

It is interesting from an operator's point of view, as well as from that of a designer, to analyze the changes in torque taking place during a ship operation from ahead to astern. Figure 146 shows a typical propeller torque curve plotted from model tests. In this curve, it is assumed that the reversal of propeller direction is rapid enough so that there is very little time for the ship to slow down from point *f* to point *d*. At point *f* of the curve the propeller turns at full-speed and provides the necessary thrust to propel the ship at full-speed. With reduction of power ahead preliminary to application of power in the astern direction, it will



A—THEORETICAL PROPELLER SPEED-TORQUE CURVE BASED ON SHIP MAINTAINING FULL SPEED AHEAD.
B—ASSUMED ACTUAL PROPELLER-SPEED CURVE ALLOWING FOR RETARDING OF SHIP.

Figure 146.—Typical propeller-torque curves.

be noted that at 60 percent of rated full power the propeller speed will drop to about 90 percent of full power revolutions per minute.

On that part of the curve extending from point *a* through *b* to *c*, the propeller acts as a water turbine that is rotated by the water streaming past it because of the ship's forward motion. When the propeller has the speed shown at point *a*, the relative direction of the water flow with respect to the propeller is substantially parallel to the propeller blades. The angle of incidence is close to zero, and the water exerts no torque upon the propeller. Neglecting friction, this is the speed at which the propeller will turn if all power from the propulsion plant is cut off. To reduce the propeller speed below that of point *a*, the propulsion plant must apply to the propeller a reverse or breaking torque, the braking torque required at each propeller speed being shown by the curve. The maximum torque that the water exerts on the propeller is reached at point *b*. Beyond this point it decreases until the propeller actually changes its direction of rotation. At point *b* it is important that the propulsion plant exerts enough torque in the astern direction to pass quickly over the hump without having to wait for the ship to slow down. The part of the curve from

c to *d* shows the torque required to turn the propeller at different speeds astern when the ship is moving through the water at full-speed ahead.

Whether or not the hump shown at point *b* will occur in actual reversal depends upon the characteristics of the ship, the propeller, and the propelling plant, and upon the way the controls are operated for the reversal. This hump has, however, shown up in numerous ship trials and on some occasions has materially affected the time in which a complete ahead to astern operation could be made. This torque characteristic has been particularly significant on certain electric-propulsion installations where motor torques as applied in the astern direction resulted in excessive motor currents. In order to overcome this condition, dynamic braking was installed on several ships. This had the effect of applying sufficient braking torque to slow down the propellers to a point where the motors could be safely reversed.

Diesel Direct Current Propulsion

PROPULSION PLANT EQUIPMENT

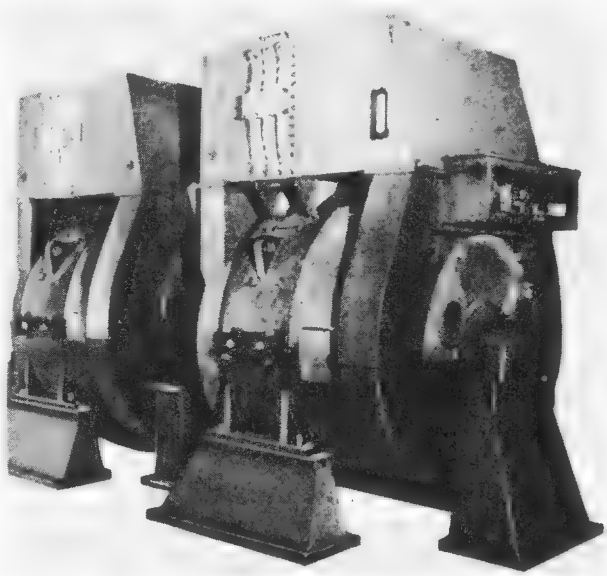
The basic equipment of a d-c Diesel propulsion plant consists of one or more Diesel-driven generators, one or more d-c motors, and the necessary electrical and mechanical control. For purposes of reliability and flexibility of operation, naval vessels are usually equipped with at least two propulsion generators and two propulsion motors for each propeller shaft. The two motors may be arranged to drive the propeller shaft through pinions and bull gear or they may be arranged in tandem on a single shaft directly coupled to the propeller shaft as shown in figure 147.

The mechanical speed reduction provided by the pinions and bull gear permits the use of higher-speed propulsion motors, whereas the tandem arrangement requires slow-speed motors.

Twin-screw Diesel vessels are generally arranged with two independent power plants, each usually consisting of two Diesel generators and two propulsion motors. These plants are separated from each other by watertight bulkheads, to minimize the effects of battle or collision damage. An installation of this type is illustrated by the arrangement of propulsion generators and motors, for an escort vessel, shown in figure 148.

In surface vessels, generators and motors of a single propulsion plant are connected in a closed ungrounded series loop as shown in the line diagram of figure 149. With this arrangement, generators and motors are connected alternately in the loop so that the potential between any two points or between any point and ground will not exceed the terminal voltage of one generator.

The control for an electric propulsion plant is designed to provide speed control of the propeller



Courtesy of General Electric Co.

Figure 147.—Propulsion motors connected in tandem.

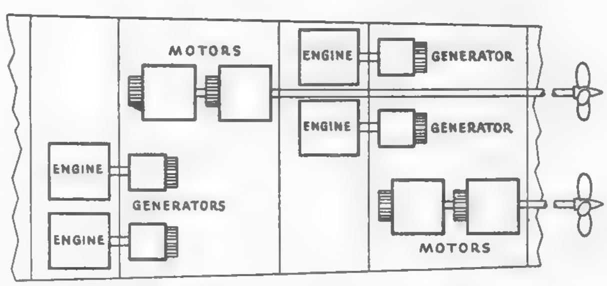


Figure 148.—Arrangement of propulsion equipment for an escort vessel.

shaft, reversal in the direction of rotation of the propeller shaft, and protection of motors and generators from sustained overloads or short circuits.

Motors of a d-c propulsion plant are shunt-wound and separately excited. The speed of shunt-wound motors is affected by change in field excitation or change in terminal voltage as shown by the speed equation.

$$S=\frac{k(V-I_aR_a)}{\Phi}$$

where S = speed
k = constant for a particular motor
V = terminal voltage
I_a = armature current
R_a = armature resistance
Φ = field flux

The most practical method of speed control with d-c electric propulsion is to vary the terminal voltage of the propulsion motors. This can be accomplished by changing the field excitation of the propulsion generators or by varying the speed of the generator prime movers. Propulsion-speed controllers combine prime-mover speed control and generator field control to accomplish the desired result of a wide range of motor terminal-voltage variation.

The limitations on motor field excitation as a means of changing propeller speed is best seen from the motor torque equation.

$$T=kI_a\Phi$$

where T = torque
k = constant for a particular motor
Φ = field flux
I_a = armature current

It has been shown that propeller torque is approximately proportional to the square of the propeller speed. Thus, in order to keep the motor-armature current within practical limits, it is desirable that the terminal voltage and motor field excitation be at a maximum when the propeller speed is at a maximum. It should also be observed that outside of this consideration the iron of motor field poles becomes saturated as the field excitation is increased beyond a certain value. This limits the speed to which a motor can be reduced by increase in field excitation, and the limit is not sufficiently low to meet propulsion requirements under maneuvering conditions.

Propulsion control does make provision for changing motor field excitation, but this is only for the purpose of making load adjustments. Consider a vessel which has become fouled. The factor k will be increased and increased torque will be required for rated propeller revolutions per minute. If the motor voltage and flux are left unchanged, the increased load will result in more than rated current. The propeller speed will be unchanged, but the propelling plant will be overloaded. If the motor fields are left unchanged and the engine speed, generator voltage, and propeller speed are decreased until the current is brought back to rated value, the propelling plant will be operating at less than rated power. Rated-power output can be maintained by increasing the motor field current which decreases the motor-speed and propeller revolutions per minute until rated propulsion loop current is obtained. When the propulsion loop current has been reduced to rated value, the propelling plant will be operating at rated engine speed, generator voltage, current, and power. The propeller speed will be less than it was before the resistance to the ship's motion was increased, but will be the highest speed obtainable without overloading the propelling plant.

A condition where the motor field is weakened for load adjustment is encountered when the propulsion plant is required to operate with less than the total number of installed generators in service. If, for example, on a two-generator, two-motor, series-loop propulsion plant, one of the generators is taken out of service, only half the normal voltage would be applied to each of the two propulsion motors. The motor speed and propeller speed would then be reduced to one-half rated value and the ship's speed to one-half the full-power speed. This would reduce the power required to propel the the ship to one-eighth of full power and the operating generator would be loaded to only one-fourth its rated capacity. Load can be increased on the generator by decreasing the motor field current. If this is done until the series-loop current reaches its full-load value, the generator will be operating at its rated capacity and each motor will develop one-half of its rated-power output.

Direction of Rotation and Speed Control

As stated previously, the speed of the propulsion motors is regulated by a combination of generator

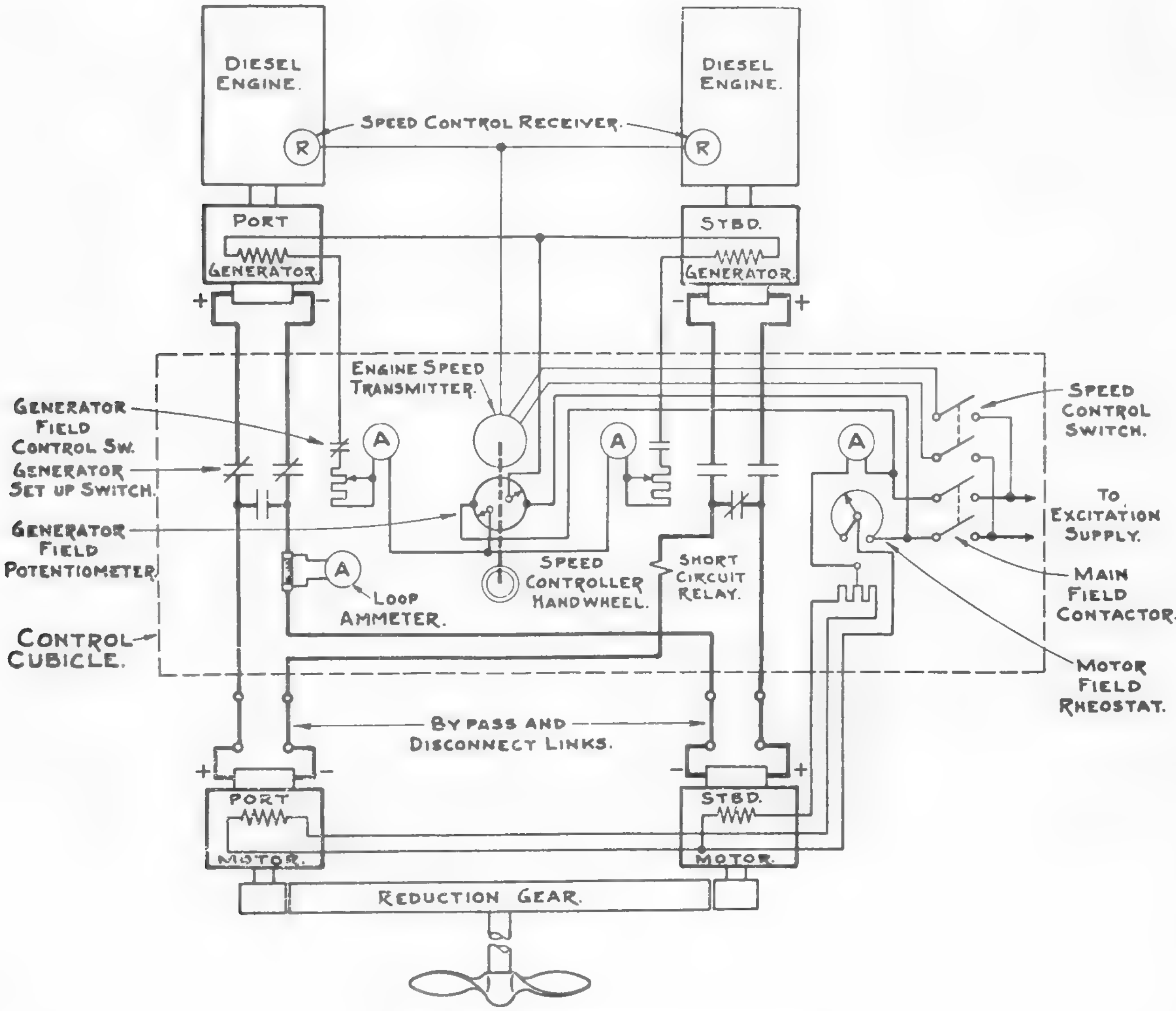


Figure 149.—Line diagram of propulsion loop.

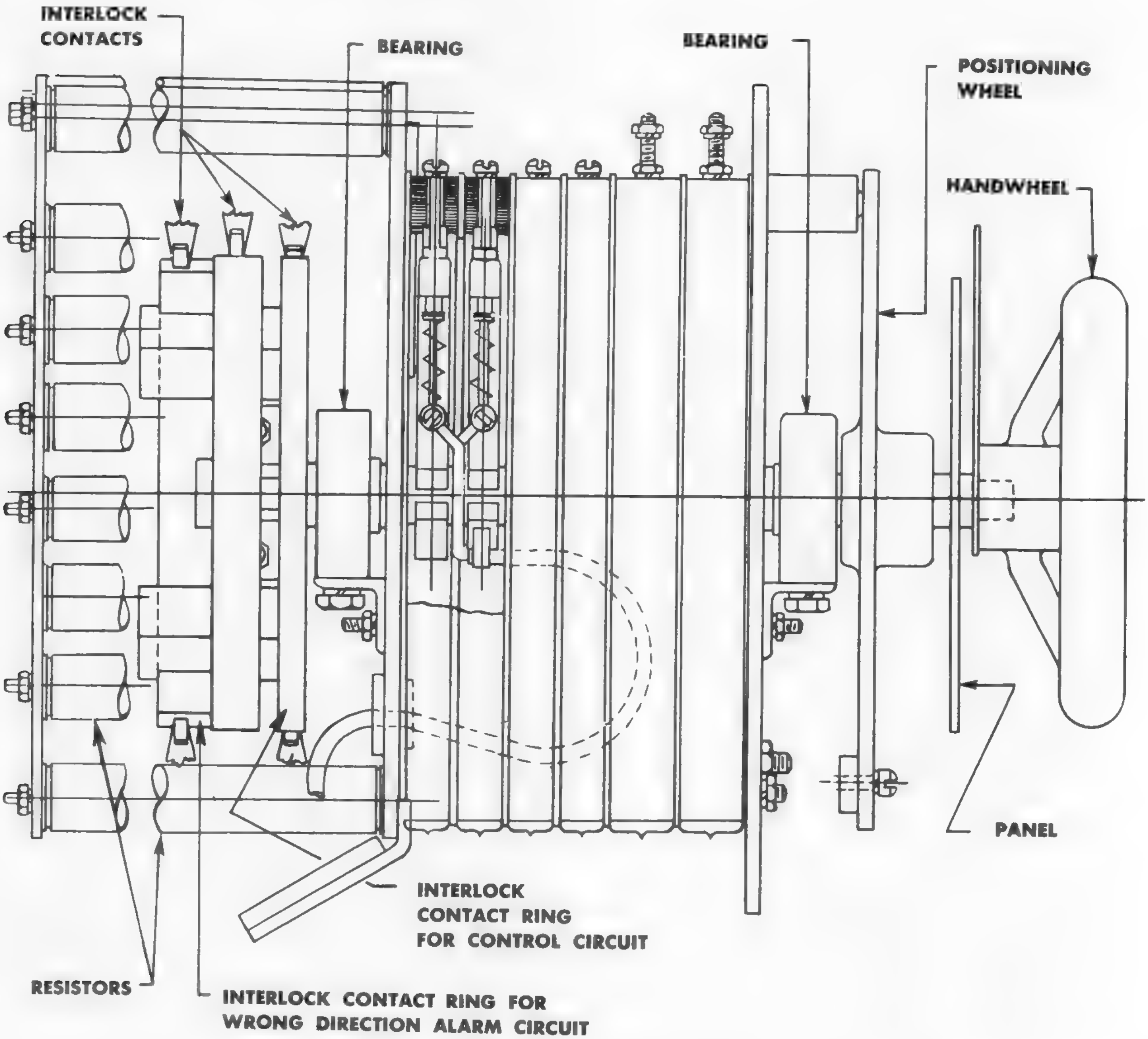
field control and engine-speed control. The direction of rotation of d-c motors is accomplished in the d-c propulsion plant by reversing the polarity of generator field excitation.

Control of motor speed and direction of rotation is performed with a single handwheel at the propulsion control cubicle or control stand, one of these handwheels being provided for each complete propulsion plant. This handwheel is connected to an engine-speed transmitter for controlling engine speed, and to a potentiometer or a rheostat and reversing contacts for controlling the direction and magnitude of the generator field current. The combined equipment is known as the speed controller; it is shown in figure 150.

The diagram of figure 151 shows the sequence of changes in generator field excitation and engine speed which take place when the speed-controller handwheel is rotated through the complete range of ahead and astern speeds.

When the speed controller is in the "Off" position, the Diesel generators rotate at idling speed and no excitation current is supplied to the propulsion generators. The handwheel is turned in the clockwise direction from the "Off" position for ahead rotation of the propeller shaft or in the

counterclockwise direction for reversed generator field excitation and astern rotation of the propeller shaft. Movement of the handwheel over about the first 50 percent of its travel varies the excitation current supplied to the fields of all the propulsion generators connected in the series loop, but leaves the Diesel-engine governors at the position corresponding to idling speed. Movement of the handwheel beyond the position corresponding to full generator field produces no further change in generator field current but operates the engine-speed transmitter to increase the engine speed. The transmitter, which may be mechanical, pneumatic, or electrical, is connected to individual receivers mounted on the Diesel engines and linked to their governors. The speed-transmitter controls the governor setting and hence the engine speed for all the generating sets in service in one propulsion loop. Some installations are provided, in addition, with individual vernier governor transmitters which furnish a fine adjustment of each engine governor separately over a limited range. This



Courtesy of Westinghouse Electrical Corp.

Figure 150.—Speed-controller handwheel.

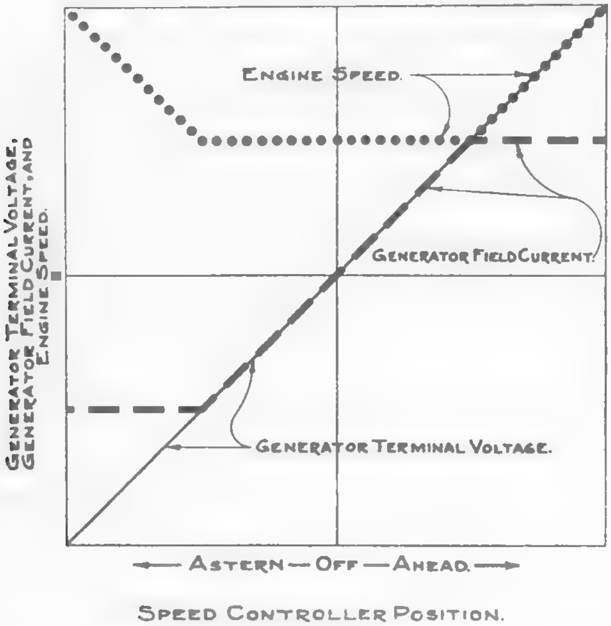


Figure 151.—Graphic representation of speed-controller operation.

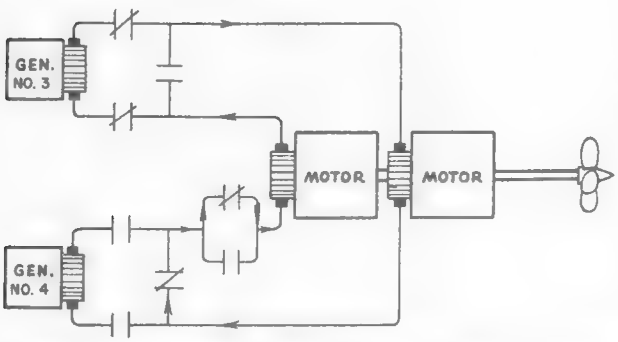


Figure 152.—Generator set-up switching (port generator bypassed).

makes it possible to equalize engine speeds if the main control does not produce exactly the same effect on each.

Motor Field-Excitation Control

In the majority of naval installations the speed controller does not change the motor field excitation. In these installations the motor field current is controlled entirely by a separately mounted motor field rheostat which is completely independent of the speed controller. There are occasional installations, however, where the speed controller changes the motor field current over a limited range but only for the purpose of reducing heating at low speeds or zero speed when the air circulation is cut down appreciably. These installations also have a separate motor field rheostat to accomplish the functions of load adjustment that have been previously explained.

Provision for Connecting and Disconnecting Generators

In any naval electric-propulsion plant, generators are removed from service or placed back in service, depending on the operating conditions of the ship. Thus, for example, a ship may maintain normal cruising speed with half of the installed generators operating but require full generating capacity for full speed. Generators may also be taken out of service for maintenance and repairs and later be put back in service when they are again ready for operation. Connection or disconnection of a generator from the propulsion circuit with the ship underway must be made with the minimum amount of disturbance to the system.

With d-c plants, a set-up or transfer switch for each generator is located on the control board to cut the generator into or out of the series loop. If a generator is to be removed from service, the set-up switch, first closes a by-passing contact, shown in figure 152, and then opens the armature contacts. Conversely, if a generator is to be placed back into service, the set-up switch first closes the armature contacts and then opens the by-pass contact. With this arrangement the series loop is always closed with either or both generators bypassed.

On a twin-screw vessel, if power is removed from one propeller shaft while the ship is underway with power on the other shaft, the idle propeller shaft and its motors will be turned by propeller drag unless the shaft is locked. Residual magnetism in the motors may cause them to act as generators and circulate current through the closed loop. This current is not large enough to be objectionable in the smaller installations but may be of considerable magnitude on such vessels as escort vessels where the shaft horsepower for each propeller may be as high as 3,000 horsepower. To prevent excessive circulating currents of this nature, each set-up switch on the large installations has a fourth contact which completely opens the propulsion loop when both set-up switches in the loop are at by-pass.

When cutting a generator into or out of the propulsion loop, there is a short period where both the armature and bypass contacts of the set-up switch are closed. This short-circuits the generator and would cause excessive currents if the generator field was exicted and there was any appreciable voltage at its terminal when the armature and bypass contacts are closed. Each generator set-up switch is therefore interlocked with the corresponding generator field switch to prevent operation of the former without first de-energizing the generator field circuit. The voltage at the terminals will then be a negligible amount when the contacts are closed.

Propulsion motors are never removed from the propulsion loop unless they are damaged. Since propulsion motors are very reliable equipment, it is very seldom that the occasion arises for taking one of them out of service while the ship is underway. Disconnecting links are therefore adequate provision for removal of motors from service. These links completely isolate the motor from the propulsion loop and a single link is generally used to reclose the loop as shown in figure 153.

Generators and motors are protected from the damaging effects of short-circuit currents by an instantaneous short circuit relay connected in the propulsion loop. This relay is usually set to trip at 250 to 300 percent of rated series-loop current and, when tripped, opens the main field contactor and removes excitation from all the propulsion motors and generators.

Protection from excessive overload currents is provided with a current-limiting relay that is usually set to operate at 110 to 125 percent of rated loop current. This relay, when actuated, inserts a block of resistance in the generator field circuit and thereby reduces the available current in the circuit. The resulting reduced field excitation will persist until the loop current is returned to rated value, at which time the relay returns to its original position and the field resistance is removed from the circuit. Connections of the short-circuit and current-limiting relays in the control circuit are shown in figure 154.

The diagram of figure 155 shows the main power and control circuits of a typical propulsion loop. If this loop is extended to include more than two generators, the principles thus far discussed will equally apply.

In the case of twin-screw surface vessel, two such

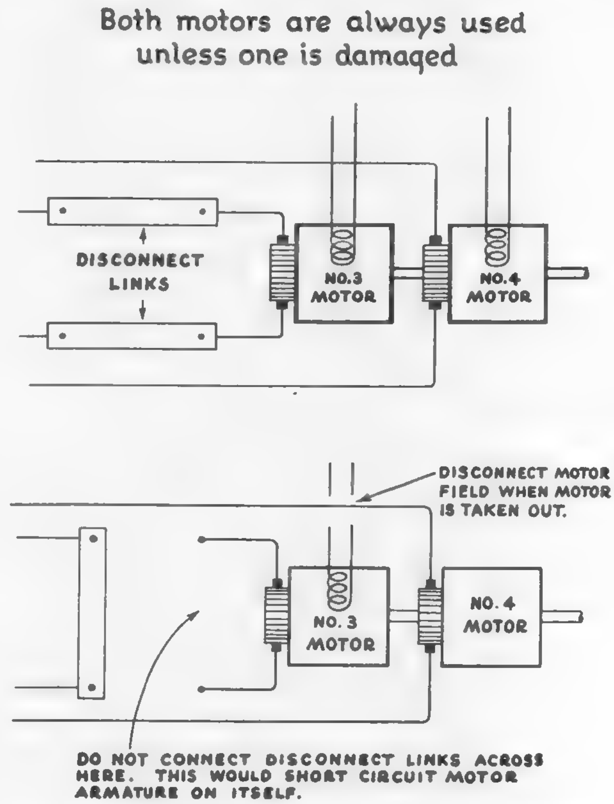


Figure 153.—Use of disconnecting links to remove a propulsion motor from service.

loops are installed, with each loop being separately controlled, usually from a separate control cubicle. The control scheme may be amplified by including remote-control stands located in the pilot house or on the bridge to permit direct control of the propulsion plant from these locations. Suitable means are provided for transferring control from the propulsion-control cubicle to the remote-control stands.

D–C Propulsion Generators and Motors

Generators for d-c propulsion plants are two-wire, separately excited, single-armature, shunt-wound machines with class-B insulation. Usually of split-frame construction they are designed for heavy-duty marine service. Interpoles are provided to improve commutation. If the Diesel engine is battery-started, the generator usually has a series field which is used only for starting purposes. The capacity of d-c propulsion generators ranges from 150 to 1,325 kilowatts at rated speeds from 600 to 900 revolutions per minute. Rated

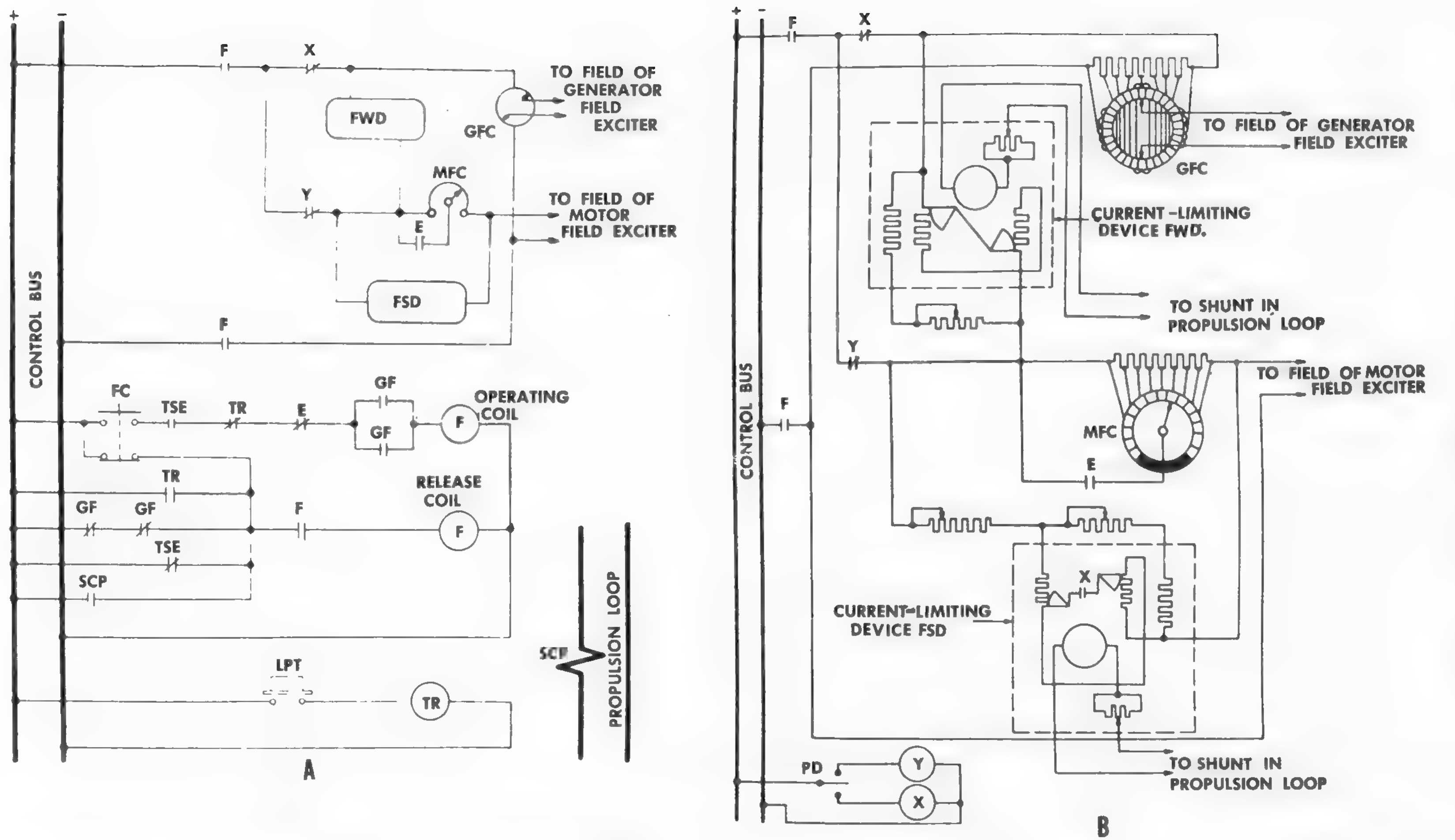


Figure 154.—Schematic diagrams of. (A) Short-circuit relay and. (B) Current-limiting relay connections. SYMBOLS: PD—Power directional relay. X and Y—Auxiliary power directional relays. MFC—Motor field controller. GFC—Generator field controller. FWD—Field weakening device. FSD—Field strenthening device. SCP—Short circuit protective relay. TR—Trip relay. LPT—Low oil pressure trip contact maker. GF—Generator field contactors. F—Main field contactors. E—Motor field reducing contactors. TSE—Exciter transfer switch. FC—Field cutout switch.

terminal voltages are from 220 volts to 1,000 volts. The voltage is kept under 1,000 volts to minimize hazards to personnel and also to eliminate the insulation problems which arise with higher voltages on d-c equipment. Bearings are usually of the split, sleeve type and are usually pressure-lubricated from the engine lubricating system.

Generators and motors are designed so that external magnetic fields produced by flow of current in the machines will be reduced to a negligible amount. This was particularly important to vessels operating in the last war that were exposed to the dangers of magnetic mines. The normal degaussing system cannot conveniently compensate for stray magnetic field that might be produced in an electric propulsion plant. The design of machines must therefore take into consideration the arrangement of terminal connections and the wiring around the frame, so there is a negligible amount of unbalanced ampere turns around the shaft.

Most propulsion generators are self-ventilated. On some of the earlier installations, air was drawn in from machinery spaces and circulated through the machines by fans attached to the rotors. This air heated by the machine windings was then exhausted into the machinery spaces where it raised the ambient temperature to excessive values. Some installations overcame this disadvantage by exhausting through ducts to the outside atmosphere, but new difficulties arose when the machines became exposed to damage from water entering or condensing in the duct-work. The best solution to the problem, and the one on which the Navy has standardized, is the use of totally enclosed machines equipped with surface water coolers. With this system the air is circulated by fans on the rotor in a continuous path through the machine windings and over the tubes of the cooler. The cooler is designed and located in the machine in such a manner as to minimize the possibility of water coming in contact with windings or commutator in the event of tube leaks or defects in the cooling system. Added protection from water damage is provided by the double tube construction (one tube inside another) required for motor and generator coolers.

A sectional view of a large d-c propulsion generator is shown in figure 156.

The following features of construction will be noted:

1. Totally enclosed with double-tube-type cooler.

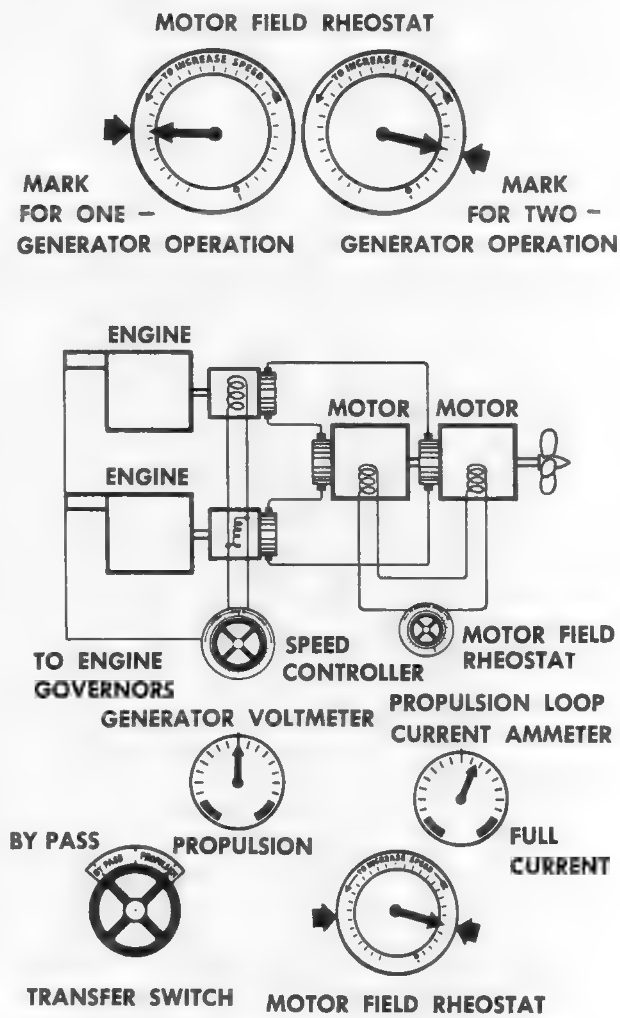


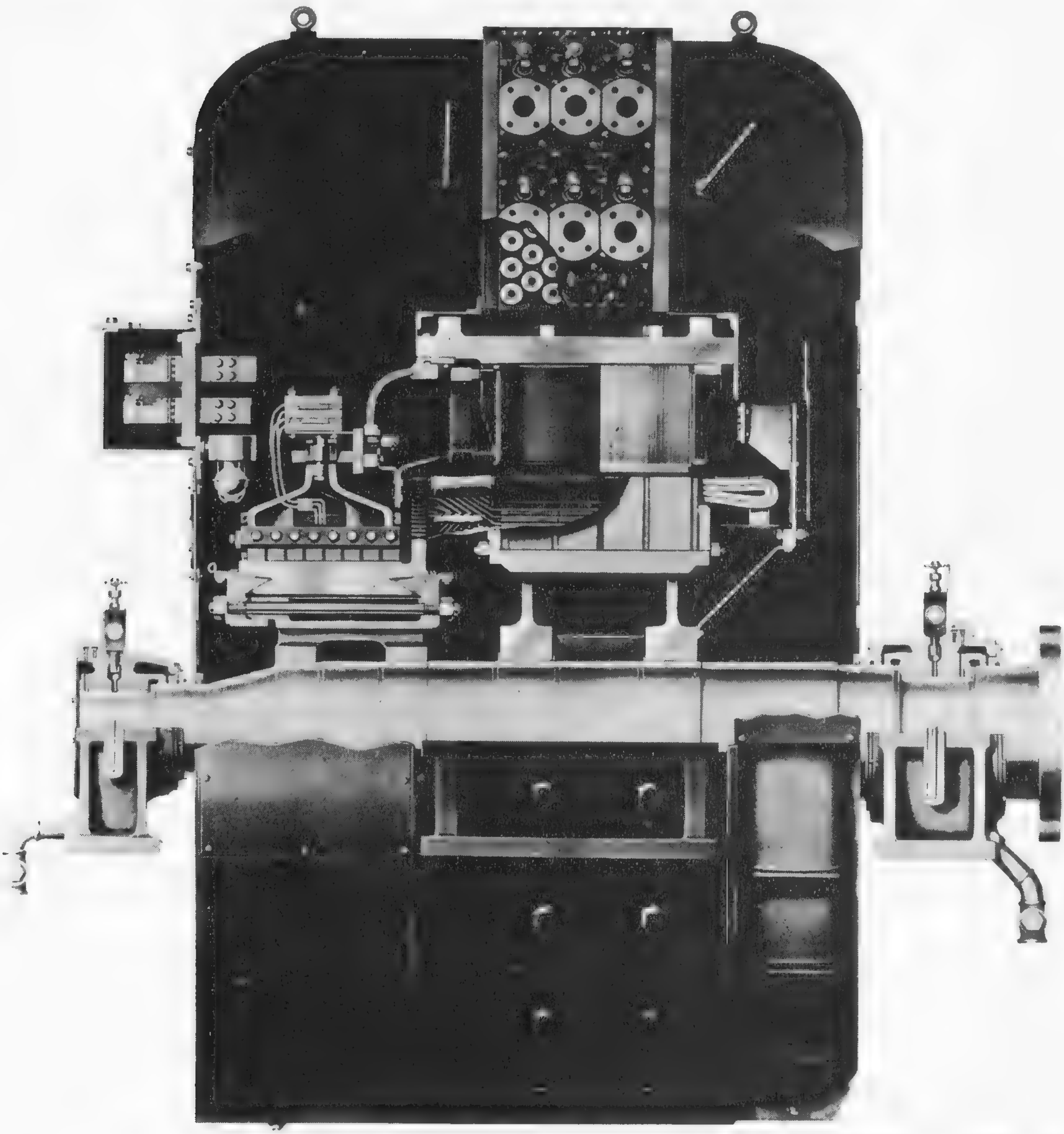
Figure 155.—Propulsion-loop power and control circuits.

2. Sleeve-type, pressure-lubricated bearings.
3. Fabricated-steel construction of frame and armature spider to reduce weight.
4. Watertight casing below shaft to protect against flooding when water level in bilges rises.

Propulsion motors that drive the propeller shaft through reduction gears are of the same general type of construction as propulsion generators. Motors are reversible and for towing applications are designed to deliver full power without overheating, over a speed range of about 75 to 100 percent of rated speed, in order to utilize the full output of the propelling plant under varying conditions of tow. The capacities range from 150 horsepower to 1,500 horsepower with rated speeds between

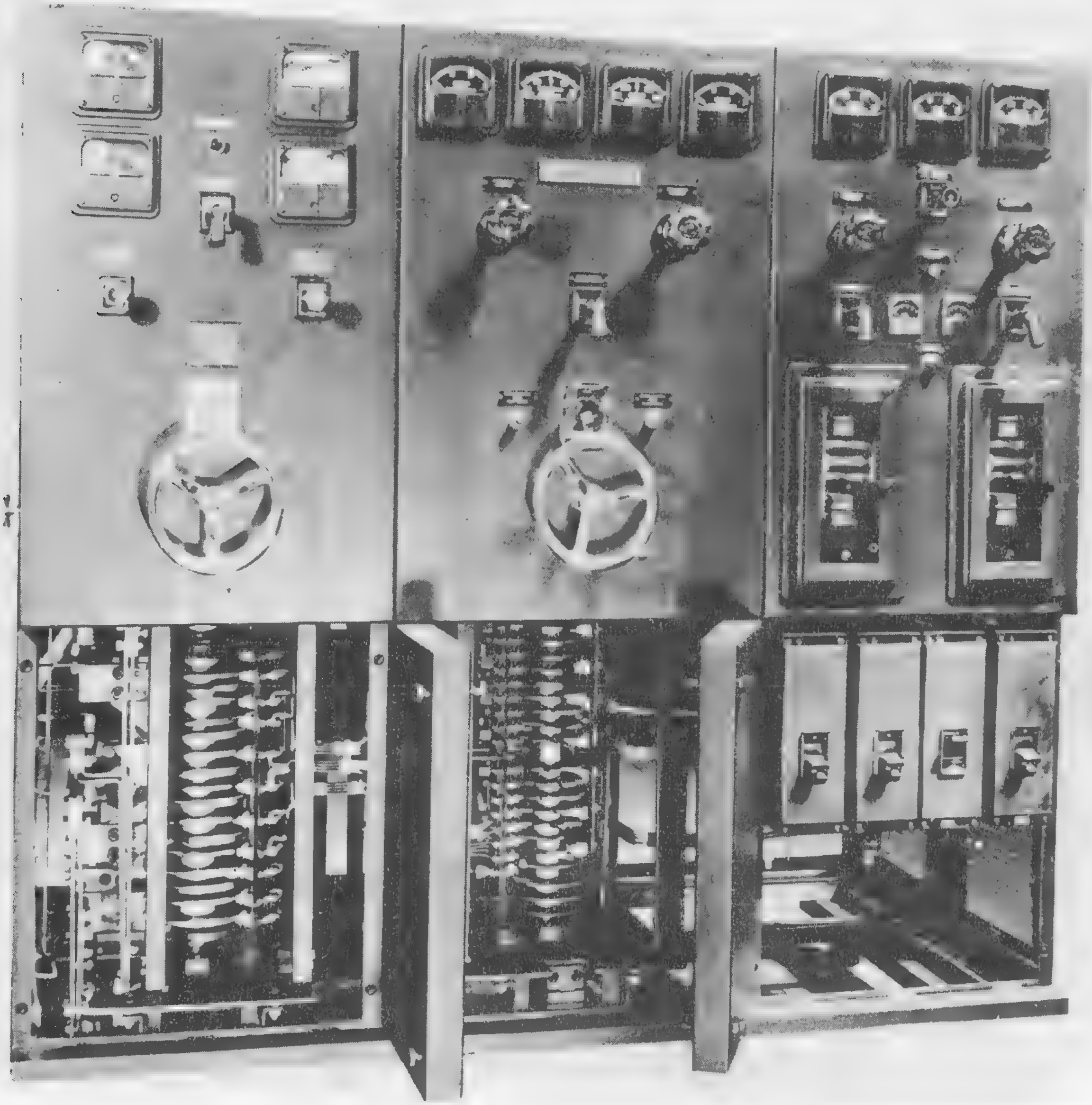
1,000 and 1,500 revolutions per minute. One, two, or four motors may be connected to one reduction gear unit.

When motors are connected directly to propeller shafts, double-armature, slow-speed types are usually applied. Single-armature slow-speed motors are, however, sometimes used. Slow-speed motors are generally of the enclosed type with water coolers



Courtesy of Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Figure 156.—Sectional view of a large d-c propulsion generator.



Courtesy of Westinghouse Electrical Corp.

Figure 157.—Typical propulsion-control cubicle.

and forced ventilation from separate motor-driven blowers. Bearings are usually self-lubricated by means of oil rings or oil disks.

Propulsion Exciters

The excitation for the fields of propulsion generators and motors is generally obtained from separate d-c generators called *exciters*. These machines can be driven by the propulsion generator engines or from motors energized from the ship's service supply. The advantage of using exciters for field excitation rather than ship's service power is in the greater simplicity of control. When the excitation is received from the ship's service constant-voltage supply, large generator field rheostats or resistors are required for generator and motor-field control, whereas if exciters are used, small exciter field rheostats are employed to deliver variable voltage to the excitation circuit.

The usual motor-driven exciter utilizes a common

motor to drive the exciters for generator field excitation, motor field excitation, and control power. Two complete sets are installed, with one acting as a standby.

Exciters are similar in construction to d-c generators of corresponding capacity installed for ship's service power systems. When motor-driven they are started from push-button stations installed at the control cubicle or located adjacent to it.

Propulsion-Control Cubicle

The propulsion-control cubicles are located in the machinery spaces. They are of the dead-front type with steel panels on which are located all indicating instruments, control levers, and handwheels. Each cubicle has a structural-steel framework enclosed on all sides with steel panels or wire mesh, within which are mounted the relays, contactors, rheostats, resistors, fuses, and associated busbar and wiring.

Figure 157 shows a typical control cubicle for a d-c propulsion plant.

Control cubicles are made up of individual sections identified as generator section, motor section, and excitation section. The major items of equipment included in a cubicle are listed as follows:

Generator Section:

1. One propulsion generator set-up switch for each generator, handwheel-operated, with necessary auxiliary contacts, interlocks, cams, shafting, etc.
2. One generator field control switch for each generator, manually operated and mechanically interlocked with its respective generator set-up switch to prevent operating the set-up switch unless the generator field excitation is de-energized.
3. One voltmeter for each generator, with zero center to indicate generator armature voltage.
4. One engine r. p. m. indicator for each Diesel generator set.

Motor Section:

1. One speed controller with handwheel to control the propeller speed and direction of rotation by control of the magnitude and polarity of the generator field excitation and the speed of the Diesel generator sets.
2. One manually operated motor field rheostat with handwheel for simultaneous control of the field excitation of all propulsion motors.
3. One set of main field excitation contactors, double-pole, magnetically operated, latched-in type, for energizing and de-energizing all the propulsion motor and generator field excitation circuits. These contactors operate in conjunction with a control switch and are also operated by tripping of the short-circuit relay.
4. On some installations, one propulsion motor field-reducing contactor interlocked with the speed controller to prevent overheating of the motor fields at standstill.
5. On some installations, one propulsion-motor field-increasing contactor interlocked with the speed controller to short out motor field resistance during starting so as to provide adequate starting torque.
6. One propulsion loop short-circuit relay, automatically reset type to trip the main field excitation contactors at approximately 300 percent of rated loop current.
7. On some installations, regulator or relay to limit the loop current during maneuvering or when sudden increments in propeller torque occur.
8. On some installations, one control transfer switch to select the local or remote speed-control station. This switch is interlocked with the main field excitation contactors to de-energize the field circuits before the transfer switch can be operated.
9. Ammeters for propulsion loop current and motor field current.
10. Voltmeters for motor armature voltages, and positive and negative lines of propulsion generators to ground.
11. Propeller shaft-revolution indicator.

Exciter Section:

1. Exciter transfer switch for selecting and connecting the normal or stand-by propulsion exciters interlocked to prevent transfer while the main field excitation contactors are energized.
2. One exciter field-control switch.
3. One exciter field rheostat for each exciter.
4. One voltage regulator for each exciter when exciters are driven by propulsion generator engines.
5. One or more voltmeters with switches for indicating excitation and control voltage and motor field and generator field voltages, and for measuring the voltage to ground of the positive and negative lines of the various excitation and control circuits.

6. Switches or circuit breakers with short-circuit protection for supplying power to propulsion excitation M–G sets and auxiliaries, as required.

It should be noted that when the propulsion generators or exciters are arranged to furnish power for auxiliary services as well as for propulsion service, additional switches and control devices are required. Since this arrangement is most often found on tankers, salvage tugs, and other auxiliary vessels requiring large amounts of auxiliary power, discussion of the additional equipment required has been purposely omitted.

Turboelectric Alternating Current Propulsion Equipment

Steam turbines are inherently high-speed machines. In all propulsion applications they require speed-reduction equipment for transmission of power from the turbine to the propeller. Electric propulsion is one method of accomplishing speed reduction and has been successfully applied on various types of naval vessels.

Where steam-turbine prime movers are used, the a-c propulsion system has a considerable advantage over the d-c system. The a-c system employs high-speed, large-capacity alternators at high-system voltage which saves considerable weight and space, as compared with the use of medium-speed, low-voltage d-c generators. Electrically propelled vessels with steam prime movers therefore utilize a-c motors and generators exclusively.

It is the usual practice on naval installations to have a separate propulsion plant for each propeller. Each plant usually consists of a single turbine alternator, one synchronous motor, and the necessary control equipment. A single motor and generator are used for each plant in place of multiple units because of the high efficiencies realized with turbines and electric machines of increased capacity and because of the reduced space and weight per horsepower.

Twin-Screw Vessels

On a twin-screw vessel the two propulsion plants can be controlled independently of each other. Provision is made, however, for interconnection of the two plants so that a single propulsion generator can be connected to run the propulsion motors of both propeller shafts. This added flexibility permits operation with a single generating unit at reduced speeds, with correspondingly improved efficiencies. It also allows inspection and maintenance of generator units while the ship is under way.

The turboelectric naval vessel follows the same general scheme for location of propulsion units as prescribed for other types of propulsion, with the individual propulsion plants separated from each other by one or more watertight bulkheads. This diversity of propulsion power minimizes the danger of a complete shut-down in the event of battle or collision damage. Escort vessels built during World War II were arranged with the propulsion units located as shown in figure 158.

Speed Reduction

The first consideration of any turbo-electric propulsion system is the fixed ratio of speed reduction between the turbine and the propulsion motors. In chapter 8 it was shown that the synchronous speed of an a-c motor is equal to

$$N=\frac{60 \times 2f}{Pm}$$

where N = speed of rotating field
f = frequency in cycles per second
Pm = number of poles

The frequency f delivered by the alternator of an electric propulsion plant to the motors is

$$f=\frac{S\,Pg}{2 \times 60}$$

where S = speed at which alternator is driven in r.p.m.
Pg = number of poles

Since the frequency is common to both alternator and motor in a propulsion plant, it follows that

$$SPg=Pm\,N$$

$$\frac{S}{N}=\frac{Pm}{Pg}$$

and

$$N=\frac{SPg}{Pm}$$

This expression is exact when synchronous motors drive the propeller shafts; but when induction motors are used, the slip at various loads must be taken into consideration. Thus, with turbine prime movers, it is to be expected that with the high speeds at which the generator is driven, a rotor with few poles would be used. The motors that drive the slow-speed propeller shafts would, on the other hand, have many poles. If, for example, the rated speed of the generator is 4,000 revolutions per minute and the rated speed of the propulsion motor is 400 revolutions per minute, there is a speed reduction of 10 to 1, and with a two-pole generator, the propulsion motor or motors would have 20 poles.

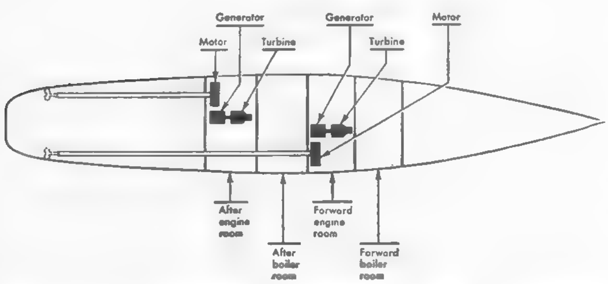


Figure 158.—Arrangement of propulsion units on destroyer escort.

Speed Control

It is obvious from the motor-speed equation that there are only two methods for varying a-c motor speed—(1) change of frequency applied to the motor and (2) change in the number of poles in the armature or stator circuit. In a few early a-c propulsion installations, pole changing was provided so that the motors could be connected to have either of two motor speeds for each generator speed (frequency). Most installations today, however, rely solely on changing the speed of the prime mover for motor-speed control. Speeds can be varied over a range of approximately 15 to 100 percent of rated maximum values by changing the speed of the prime mover alone, and this is considered a sufficient range for most applications.

Synchronous Motors

The marked improvements in the design and operating characteristics of synchronous-motor starting windings has made the synchronous motor suitable for application on a-c propulsion systems. These improvements have resulted in higher torque and lower current inrush during starting. Because of this ability to supply adequate starting and reversal torque and its more desirable electrical and mechanical features, as compared with the induction motor, the synchronous motor is now used for all new a-c propulsion installations. The pole-changing feature used in the early installations is no longer considered to be worth the additional complications involved and is not provided. The typical turbo-electric plant, therefore, utilizes synchronous propulsion motors and speed control which is entirely regulated by changes in speed of the prime movers.

Starting of Synchronous Motors

Polyphase synchronous motors for propulsion service are provided with bars in the field pieces of the rotor which are connected to form a squirrel-cage winding. This winding enables the motor to start as an induction motor and to reach a speed that can be synchronized with the rotating magnetic field. During the starting period the rotating magnetic-field links and cuts the field coils of the rotor at a rate equal to the difference between synchronous speed and rotor speed. Since these field coils have a relatively large number of turns and are connected in series, extremely high voltages are induced in the field circuit when starting and reversing. To prevent insulation failure, the field circuit is usually closed through an external resistor that permits current to flow in the circuit so that most of the induced voltage is utilized as reactance drop in the field windings.

The starting torque produced by the squirrel-cage winding is capable of bringing the rotor up to approximately 95 percent synchronous speed. At this point, the external resistance is removed from the field circuit and the field is excited from a d-c power source. When the rotor poles become magnetized, they tend to pull into step with unlike poles of the rotating magnetic field. When the poles are properly excited, this additional torque is sufficient to lock the rotor in step with the rotating field and the motor runs at synchronous speed. Line current will show a considerable amount of fluctuation after excitation is applied until the machine pulls into step. This is due to the momentary slipping of rotor and stator poles past each other just before synchronism is attained. As soon

Courtesy of Westinghouse Electrical Corp.

Figure 159.—Propulsion-control levers.

as the motor pulls into step, line-current fluctuations of this nature will cease, and the operator will know from the ammeter that the machine is synchronized.

In order to secure a high torque at starting, a higher-than-normal voltage is applied by overexciting the generator field. When the motor has accelerated to a speed approaching synchronous speed, motor field excitation is applied at a value in excess of normal. This insures adequate pull-in torque for synchronizing. Motor and generator field excitations are both reduced to normal after the motor or motors are running at synchronous speed. It should be noted that the turbine prime mover is set to run at about 20 percent of normal speed throughout the entire starting operation.

Reversing

When a motor is to be reversed, the turbine speed is first brought down to slow or maneuvering speed. The field excitation is then removed from both motor and generator fields and two-line leads are interchanged. The motor is restarted as an induction motor in the opposite direction of rotation and resynchronized as before.

Power Factor

The power factor at which a synchronous motor operates can be controlled by the motor field excitation. Overexcitation of the motor results in leading power factor, whereas under excitation causes the motor to draw lagging power-factor current.

The field excitation of propulsion motors running at synchronous speed is maintained at a 100 percent power factor. With this adjustment, the armature currents of both motors and generators are kept at a minimum for all running-load conditions.

Single-Generator Operation

In the typical turbo-electric installation, provision is made for connecting the motor of each propulsion shaft to a single generator. Before making these connections, turbine governors are adjusted for slow or maneuvering speeds and field excitation is removed from all motors and generators. The motors are then connected to a single generator and operations for starting, synchronizing, and running are performed as previously described.

Propulsion-Control Equipment

It would appear that a considerable number of manually operated control devices would be required to accomplish the starting and reversing sequences as outlined above and that personnel with a wide background of electrical experience would be needed to properly execute the necessary procedures. Control equipment provided with the a-c propulsion plant, however, reduces the number of manually controlled devices to a minimum. Furthermore, these devices are mechanically and electrically interlocked so that improper operation is practically impossible.

The control for starting, running, and maneuvering the typical turbo-electric plant is usually operated from three levers at the control cubicle. These levers are known as the reverser lever, the field lever, and the speed lever or turbine governor lever; they are shown in figure 159.

Additional levers are provided to connect two motors to a single generator and to control the turbine speed directly from its throttle in the event of a

governor failure. These levers are known as the *motor set-up lever* and the *emergencu control lever*, respectively.

Reverser Lever

The reverser lever operates mechanically to close or open contacts in the power circuit connecting the generator to the motor. The sequence of operation is as shown in the diagram of figure 160. These contacts are not intended to open or close the power circuit when either motor or generator fields are excited. Interlocks are therefore provided between the reverser lever and the field lever so that the reverser lever cannot be operated unless the field lever is in the "Off" position, or the field lever cannot be operated if the reverser lever is in the "Off" position.

In some installations, astern speed is limited to the two-thirds speed position of the turbine governor lever by an interlock which prevents movement of the turbine governor lever if the reverser lever is in the astern position.

Field Lever

The field lever is used to operate contactors which energize the generator and motor fields. It may have four positions, as shown in figure 161, which mechanically open and close contacts in the generator and motor field circuits to set up the various conditions of excitation required for starting and running a propulsion motor.

The essential features of propulsion field control are shown in the simplified field circuits of figure 161. When the lever is placed in position "One," the generator field contacts 6, 7, 8, and 9 close and the generator field is directly connected to the excitation bus. By shunting out the generator field resistor with contact 9, the generator field is excited with approximately 300 percent normal field current. Contacts 10, 11, and 12 in the motor field circuit remain open and the motor starts as an induction motor. When the lever is placed in position "Two", motor field contacts 10, 11, and 12 are closed and the motor field is directly connected to the excitation bus. By shunting out the motor field resistor with contact 12, the motor field is overexcited. At the same time contact 9 opens and a portion of the generator field resistance is inserted into the generator field circuit, reducing the excitation to approximately 120 percent of normal value. The motor pulls into step a few seconds after position "Two" is reached and runs as a synchronous motor. As soon as the motor is synchronized, the field lever is placed in the "Run" position. This position opens contacts 8, 9, and 12 and the full values of resistances are inserted into the generator and motor fields respectively, reducing their excitations to the normal rated values.

Positioning of the field lever from "Off" to "Run" should be excuted with caution against lingering on positions "One" and "Two" beyond the time necessary to start and synchronize the motor. The squirrel-cage winding which is utilized for induction-motor starting in position "One" is only intended for starting duty, and if there is an appreciable delay in synchronizing after the motor has come up to speed, this winding will overheat

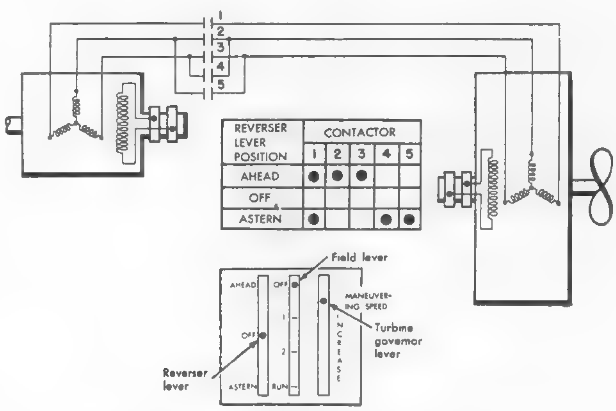


Figure 160.—Reverser lever sequence of operation.

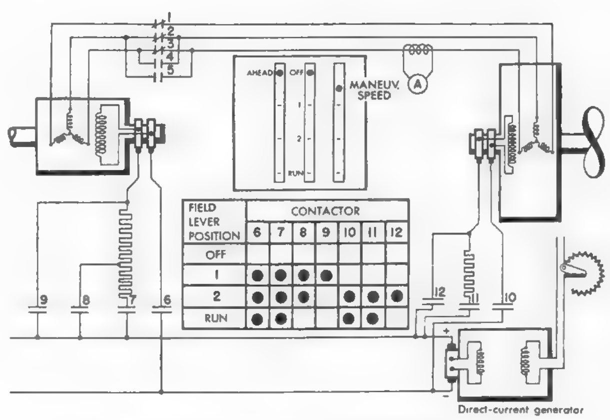
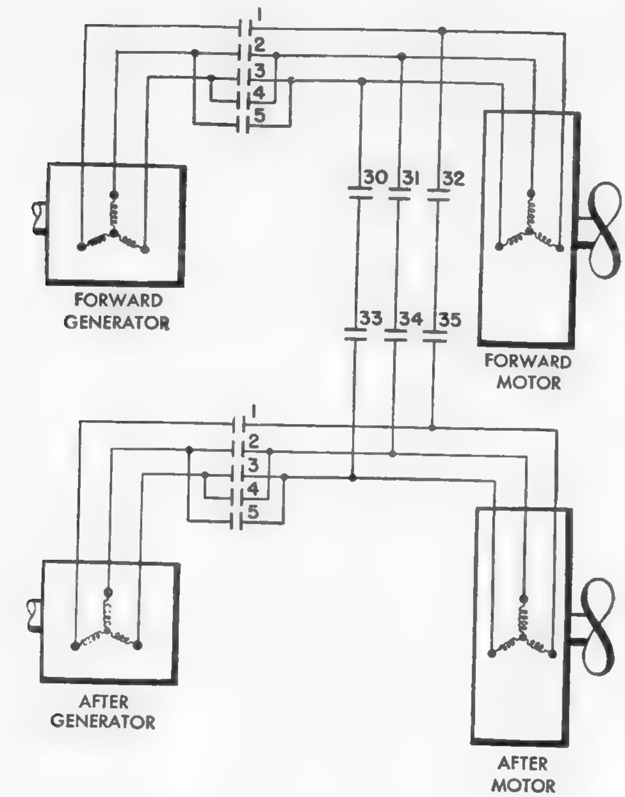


Figure 161.—Operation of field-control lever.



MOTOR SET-UP LEVER

FORWARD

LEVER POSITION	CONTACTORS 30	31	32
ONE MOTOR			
TWO MOTORS	●	●	●

AFTER

LEVER POSITION	CONTACTORS 33	34	35
ONE MOTOR			
TWO MOTORS	●	●	●

Figure 162.—Operation of motor set-up lever.

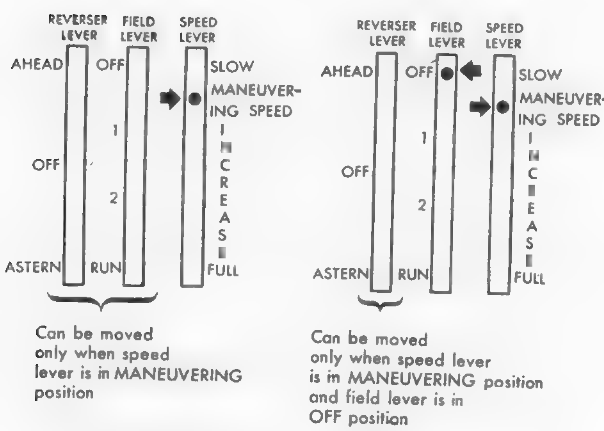


Figure 163.—Simplified diagram of mechanical interlocks.

and possibly damage the motor. Furthermore, the generator field is overexcited in the "One" and "Two" positions and the motor field is overexcited in the "Two" position. Any appreciable delay in shifting from these positions into the "Run" position will cause overheating of the field windings.

The actual field control circuit of a typical a-c propulsion plant contains numerous contacts of the motor set-up lever for proper inter-connection of motor fields when two motors are set up to operate with a single generator. Provision is also made for connection of a resistor across the motor field when the field lever is in position "One" and the motor is operating as an induction motor. This is to prevent excessive induced voltages from building up in the field winding.

The field lever is mechanically interlocked with other operating levers to insure the proper sequence of operations for reversing, starting, synchronizing, and running. The interlocks with the reversing lever have been previously described. The operation of other levers with the field lever are governed by interlocks as follows:

1. The turbine governor lever cannot be moved beyond maneuvering speed unless the field lever is in the "Run" position; however, this interlock is ineffective if the emergency lever is in "Stop" or a speed control position. (See figure 163.)

2. The field lever cannot be moved from the "Run" position unless the turbine governor is in the maneuvering position or slow-speed positon. This interlock is ineffective when the emergency lever is in "Stop" or a speed-control position.

3. The emergency lever cannot be moved to a speed-control position unless the field lever is in other than the "Off" position. Conversely, the field lever cannot be moved to the "Off" position if the emergency lever is in a speed-control position.

Motor Set-up Lever

The motor set-up levers are used to operate contactors which connect the two propulsion-motor field and armature circuits in parallel or which connect them for single operation. Each motor set-up lever has two positions, "One-motor" and "Two-motor". Typical operation is as shown in the simplified diagram of figure 162. When the lever is in the "One-motor" position, the generator supplies power to one motor only. If one of the generators is shut down, the motor set-up lever in each

engine room may be put in the "Two-motor" position. This connects the motors in parallel, and operation is controlled by levers on the panel of the operating generator. The motors operate from a single generator and their fields are paralleled and connected to either the forward or after excitation bus.

Mechanical and electrical interlocks between the reverser lever and the set-up lever govern the operation of these levers as follows:

1. The set-up lever cannot be moved to the "Two-motor" position unless the reverser lever is in the "Off" position (mechanical).

2. The set-up lever cannot be moved to the "Two-motor" position unless the reverser in the other engine room is in the "Stop" position (electrical).

3. The reverser lever cannot be moved from the "Stop" position unless the reverser in the other engine room is in the "Stop" position or one of the two set-up levers is in the "One-motor" position (electrical).

Protective Devices

The protective devices in the typical a-c propulsion installation include phase-balance relays and ground relays.

Phase-balance relays operate in conjunction with magnetic contactors to remove the generator and motor field excitation when there is a phase unbalance of 25 percent or more. This protects the system against single-phase short circuits or single-phase operation. The type of relay installed on the DE51 class escort vessels operates on the induction principle.

Each relay has two driving elements acting on opposite sides of its disk. One of these, the operating element, drives the disk in the contact-closing direction, and the other, the restraining element, rotates the disk in the contact-opening direction. The operating coil of each relay is connected in series with the restraining coil of another relay. The restraining coil has 25 percent more turns than the operating coil; therefore, a relay will not operate (contacts will not close) unless the current in its operating coil increases to at least 125 percent of that in its restraining coil. The contacts of the three relays are connected in parallel, so that the operation of any relay will complete the tripping circuit and open contactors located in the generator and motor field circuits.

The ground relay on DE51-class escort vessels has a single operating coil which is connected to a current transformer in the generator neutral line. When one of the generator phases becomes grounded, current flows into the grounded neutral line and thereby energizes the coil of the ground relay. This causes the relay disk to rotate and close its contacts so that it completes the tripping circuit.

Time delays are provided on both phase balance and ground relays to prevent false operation under momentary surge conditions.

Voltage Regulation

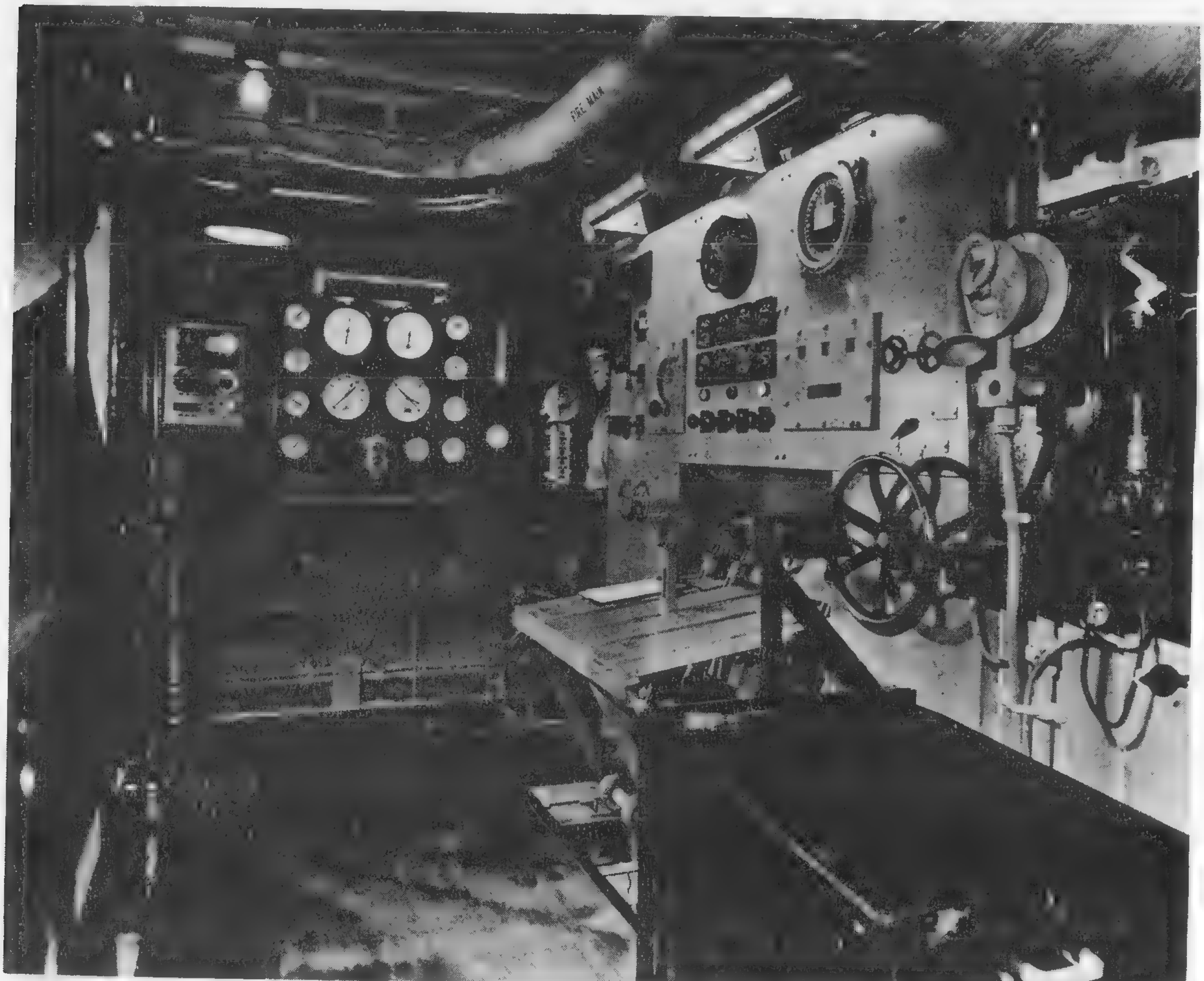
When steam turbines are used as prime movers, the inertia of the rotating mass is much higher than when Diesel engines are used. Consequently, momentary increases in propeller torque will not result in perceptible speed changes. When a vessel is under way in rough seas, these increases in torque may be substantially above normal torque requirements and the system must be designed to accommodate them.

By maintaining a constant ratio of frequency to voltage in the system at unity power factor under all conditions of torque variation, motors and generators can be designed with a torque margin as low as only 5 percent of rated torque. This is accomplished by the use of quick-acting voltage regulators, usually of the rotary amplifier type. The operation of this type of regulator as applied to ship's service power systems has been previously described in chapter 5. This discussion of its operation in propulsion field-excitation circuits is reserved for instruction books on specific installations. It will be noted, however, that the voltage regulator is connected with contacts of the field circuits so that it functions to supply the over-excitation of motor and generator fields during the starting period. Provision is made with a selector switch for connection of the excitation circuit to either the voltage regulator for automatic control or to an exciter field rheostat for manual control.

Metering

The meters on the typical control cubicle for a turbine a-c propulsion plant include the following:

1. Generator field ammeter.
2. Generator indicating wattmeter.



Courtesy of General Electric Co.

Figure 164.—Front view of control cubicle.

3. Motor field ammeter.
4. Voltmeter with selector switch for exciter volts or ground detection.
5. Generator line ammeter.
6. Generator voltmeter, which indicates voltage at terminals of propulsion generator.
7. Turbine speed indicator.
8. Temperature indicator with selector switch for generator and motor stator windings.
9. Shaft rpm indicator and revolution counter.

Load-Limit Control

Load-limit control is operated from a handwheel on the propulsion control cubicle. It can be used in two ways:

1. It can be set to limit the maximum amount of steam flow, in order to eliminate variations in steam flow to the turbines resulting from speed changes caused by varying propeller torque in a seaway. This feature in combination with voltage regulation helps to reduce the peak currents imposed on generators and motors in the propulsion circuit.

2. It can be used to secure fine speed adjustment.

In addition to equipment previously described, the typical control cubicle also contains the following items of equipment:

Engine-room telegraph.
Stand-by exciter control switch.
Exciter field rheostat.

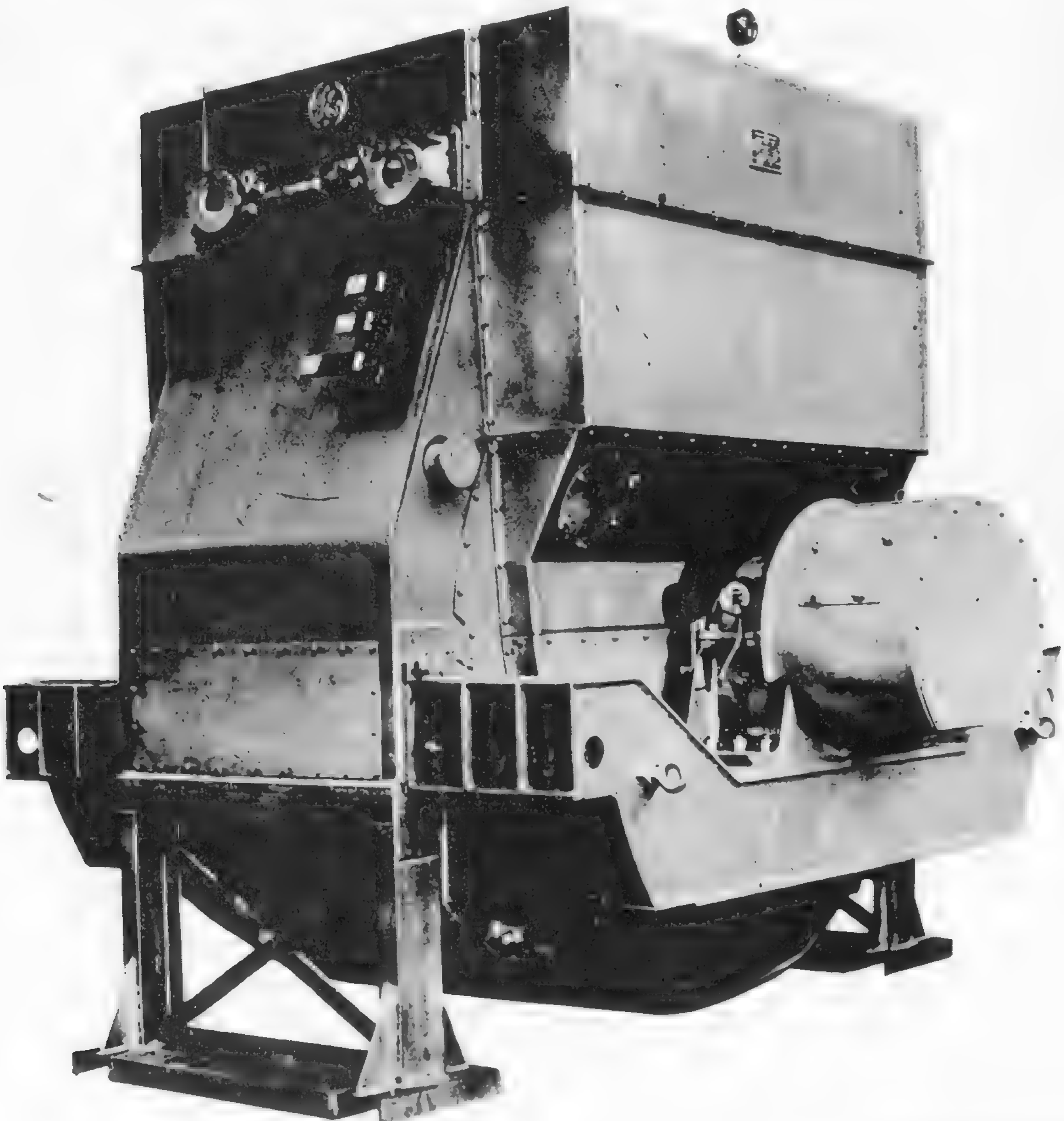
Turbine emergency trip handle (causes turbine throttle to close by spring action when operated). A typical control cubicle is shown in figure 164.

A-C Propulsion Motors and Generators

The propulsion generators of turbine a-c propulsion plants are cylindrical rotor, high-speed machines. They are completely enclosed and are equipped with salt-water cooling coils of double-tube construction. Air circulation through generator windings and the cooler is provided with ventilating fans attached to the rotors.

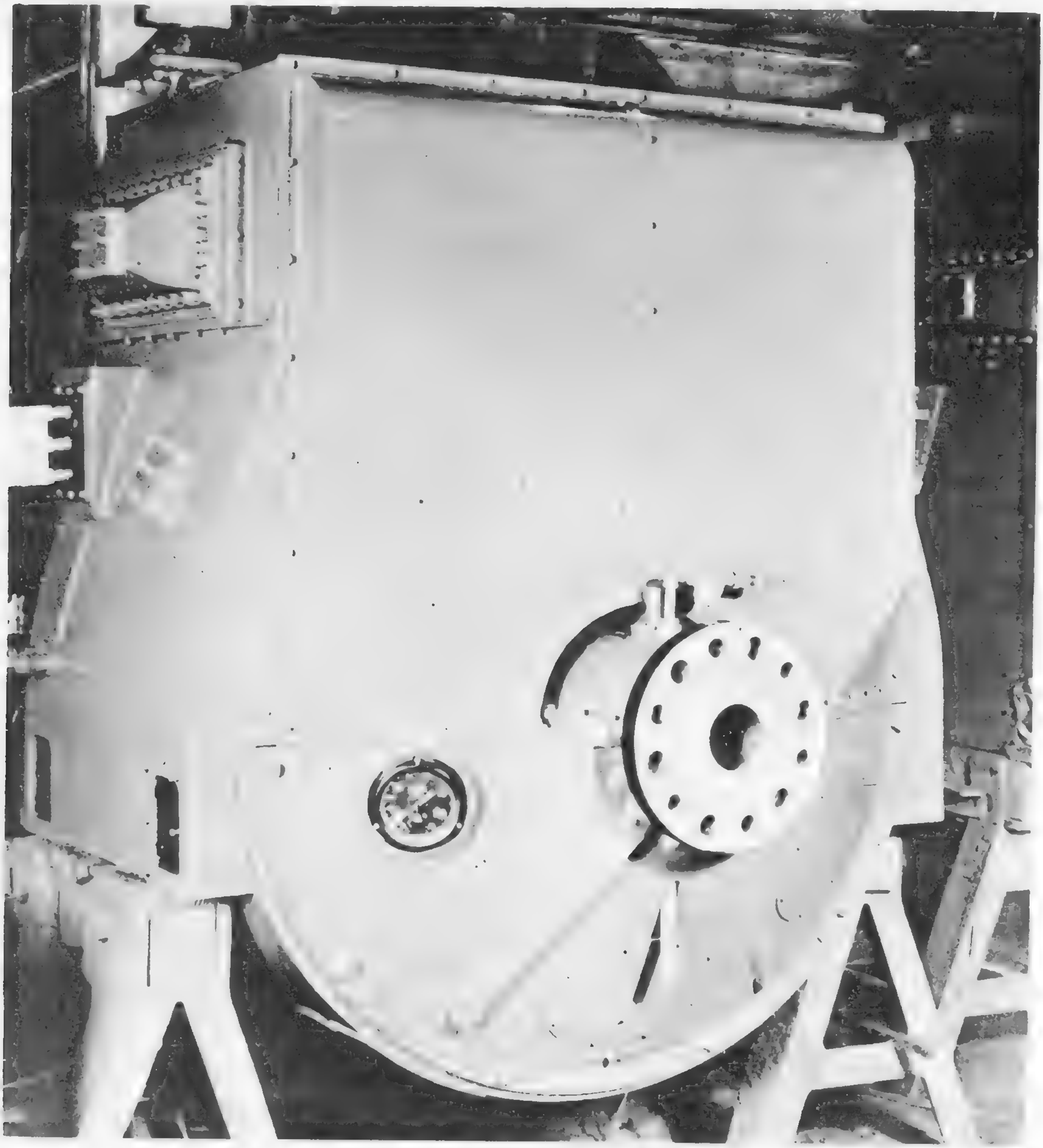
The general appearance of typical propulsion motors and generators is shown in the photographs of figures 165 and 166.

A–c propulsion motors are salient pole, syn-



Courtesy of General Electric Co.

Figure 165.—Typical a-c propulsion motor.



Courtesy of Westinghouse Electrical Corp.

Figure 166.—Typical a-c propulsion generator.

chronous machines with damper windings in the pole faces. They are totally enclosed and are provided with water-to-air heat exchangers of the same general construction as generator coolers. Motor-driven blowers are installed to furnish the required air circulation at all propulsion motor speeds.

CHAPTER 13

SAFETY PRECAUTIONS

Importance of Safety

Experience is not to be depended upon as a teacher of safety in any kind of work. This is particularly true in electrical fields where all too often the first mistake is the last one. For that reason the importance of safety must be impressed on all men engaged in operating and maintaining electrical equipment aboard ship.

Potential danger lurks in all electrical circuits regardless of whether the voltage is high or low. On ships, where contact with energized circuits is a particular hazard, lack of caution in working with low voltage is often the cause of fatalities. Supposedly unenergized circuits like the unloaded gun are also sources of tragedy for the careless and unwary. The underlying reason for almost all of these electrical casualties is the failure to observe the fundamental rules of safety.

Electricians should therefore be made safety conscious with a continuous program of safety teaching that reaches every man. In such a program it is not sufficient to issue a set of instructions that may be read once and then promptly forgotten. Precautions must be orally presented at regular intervals until the force of repetition makes them second nature to all hands. To implement these presentations, question and answer drills are recommended as a highly successful teaching device. This safety program should include all rates and all levels of experience. Contrary to popular belief, it is not always the young men who are least vigilant. Carelessness with regard to personal safety is often more predominant among older hands who in haste to get a job done sometimes disregard the most elementary safety practices.

Certain technical aspects of electric shock should be stressed in order that the need for, and the nature of, safety precautions may be properly appreciated. To begin with, current rather than voltage is the proper criterion of shock intensity. If 60-cycle alternating current is passed through a man from hand to hand or from foot to foot, the effects noted when the current is gradually increased from zero are as follows:

At about 1 milliampere (0.001 ampere) the shock is perceptible.

At about 10 milliamperes (0.010 ampere) the shock is of sufficient intensity to prevent voluntary control of the muscles. Thus, the man may be unable to let go and free himself from the electrodes through which current enters his body.

At about 100 milliamperes (0.100 ampere) the shock is fatal if it lasts for 1 second or more.

These figures are approximate only because men differ in their resistance to electric shock, but the results of a number of investigators show that the figures given above correctly represent the order of magnitude of 60-cycle currents that will produce the effects indicated. It has also been found that 60-cycle alternating current is even more dangerous than current of lower frequency, including direct current of zero frequency. The difference is not very large, however, and the same measures that are used to protect personnel from shock by 60-cycle alternating current should also be used to protect personnel from shock by direct current.

In any consideration of safety from electric shock, it is imperative to recognize that the resistance of the human body cannot be relied upon to prevent a

fatal shock from 115-volt or even lower voltage circuits. To be sure, when the skin is dry, it interposes a high resistance even when it makes contact with bare conductors. The resistance may be high enough, in this case, to protect a man from fatal shock even if one hand touches a bare conductor on one side of a 115-volt line while the other hand touches a bare conductor on the other side of the line. On board ship, however, it is far more likely that the skin will be wet with perspiration or salt water. The contact resistance falls when the skin is wet, and the body resistance measured from electrode to electrode is low. Tests made by the National Bureau of Standards show that the resistance of the human body may be as low as 300 ohms under unfavorable conditions, such as are encountered on naval vessels, because of the presence of water and perspiration. If 0.1 ampere is enough to cause death and if the body resistance can be as low as 300 ohms it follows that 115-volt circuits can supply more than enough current to be fatal.

Electric current will pass through the body of a man whenever his body forms a part of a closed circuit on which is impressed an electromotive force or a difference in potential. Contact with two sides of a power line is perhaps the most obvious means of closing an electric circuit through the human body, and needs little explanation to laymen or electricians. Precautions against this type of accident on shipboard are taken care of in the design of equipment by enclosing all live parts in grounded metal enclosures. As part of his responsibility for maintaining equipment the electrician must open enclosures for inspections and adjustments. Inspections, of course, must sometimes be carried out with circuits energized but such inspections should be confined to observation only. This must be carried out with a considerable amount of caution so that no part of the body is exposed to the danger of contact with live parts. Insulated tools should always be used when its is necessary to conduct a test by manual movement of a current-carrying part. When a circuit is to be worked on, it should be de-energized prior to doing any work. In de-energizing a circuit to be worked on, it is not enough to open a switch at the switchboard or distribution panel. There are too many chances of making the fatal mistake of improperly identifying a feeder number or even the legends of nameplates on switches or circuit breakers. Before work proceeds the next step is to test the power-supply terminals at the equipment with a voltage tester for assurance that the circuit is dead. Having determined that the circuit *is* de-energized, switches or circuit breakers should then be properly tagged to prevent closure by other personnel. Circuits should be checked to see that they cannot be energized through bus-transfer switches.

Shipboard electrical systems are ungrounded and the current leakage is minute. The current leakage increases with the size of the system. No insulation is perfect. All insulators partially lose their property under conditions of dampness or actual structural damage. It is extremely dangerous, therefore, to handle a single live conductor at any time.

One important way in which naval shipboard systems become grounded has been recently recognized and is specifically mentioned because of the unusual way in which it occurs. This grounding is brought about by the installation of radio-interference suppression filters. These filters contain capacitors connected from ground to each of the phases (or conductors) of the electric power distribution system. The purpose of the filters is to suppress radio interference, not to ground the distribution system. Nevertheless, their effect, particulary when a large number is used, is effectually to ground an a-c distribution system insofar as personnel safety is concerned. This is not a condition that will show up when a d-c insulation-resistance measuring instrument is used. The insulation resistence of a system including the filters can show up as infinity in tests but yet the magnitude of alternating current or fluctuating direct current that can pass through the filters to ground may be enough to cause fatal shock.

No discussion of electrical safety precautions is complete without mention of current transformers. The main thing to remember is that the secondary circuit should never be opened when the primary circuit is carrying current. The high turn-ratio between primary and secondary circuits causes dangerously high voltages to be induced in the secondary even when the primary voltage is only a fraction of a volt. The dangers of current transformer open secondaries has occasioned the use of automatic devices in some installations to short circuit the terminals of current transformers when the secondaries are inadvertently opened.

From these considerations it must be concluded that contact with any single live part of a ship's

electrical plant is apt to be fatal. It is only a matter of luck when a shock does not occur or that a shock is not sufficiently intense to result in death.

WORKING ON LIVE CIRCUITS

While it is impossible to list all the specific precautions to be observed in avoiding contact with current-carrying parts of electrical equipment, certain general precautions should become a part of any working code as applied to shipboard electrical systems. These are:

1. Never be in too great a hurry to repair an electrical circuit. Haste can make waste in human life when applied to electrical equipment.

2. Treat all circuits with caution regardless of their respective voltages.

3. Except in cases of emergency, never work on an energized circuit. The circuit must be considered as energized until a personal check has been made and the switch is opened and tagged.

4. When military considerations require that electrical repair or maintenance work be performed, but prohibit de-energizing the circuits involved, use extreme measures of precaution. The work should be accomplished only by adequately supervised personnel fully cognizant of the dangers involved. Every care should be taken to insulate the person performing the work from ground and to use all practicable safety measures. The following precautions should be taken when applicable:

a. Provide ample illumination.

b. See that all rings, bracelets, and wrist watches are removed by the person doing the work.

c. See that clothing and shoes are as dry as possible.

d. Cover working tools made of metal with insulating rubber tape (not friction tape), insofar as practicable.

e. Insofar as practicable, insulate with tape or other suitable material any live metal parts immediately adjacent to the work to be done.

f. Use only one hand in accomplishing the work, if practicable.

g. Use a rubber glove on the hand not used for handling tools. If the work being done permits, wear rubber gloves on both hands.

h. Have men stationed by circuit breakers or switches, so that the circuit or switchboard can be de-energized in case of emergency.

5. Regard all electrical leads as alive until proved otherwise. To check a circuit, test the live side (or a live circuit) with a voltmeter, voltage tester, or test lamp to make sure the device works, then test the dead side with the same device and retest the live side, to make sure the testing device is still in good condition.

6. Because of the extreme hazard involved, never take a shock intentionally. Whenever it is necessary to check a circuit to see if it is alive, a voltmeter, voltage tester, test lamp, or other suitable indicating device should be used.

7. Never implicitly trust insulation on live circuits. Insulation may look perfect yet still not prevent a fatal shock.

8. Carefully select and maintain all portable cables. They should be of the proper length and cross-sectional area. Spliced portable cables are extremely dangerous and should not be used, unless an emergency warrants the risk involved.

9. Remove, or replace only fuses of 10-ampere capacity or less using fuse pullers made of insulating material for removal or replacement. Fuses larger than 10-ampere rated capacity should be removed and replaced only after the circuit has been completely de-energized. Replace a blown-out fuse with a fuse of the same rated ampere capacity. Never short out a fuse.

10. In actuating circuit breakers and switches, take the following safety precautions. Before closing any circuit breaker or switch be sure that:

a. No one is working on the circuit.

b. The circuit is ready, with all equipment connected to it in condition to be energized.

c. All circuit protective devices are in good working order.

d. Only one hand is used when operating a circuit breaker or switch. The other hand should be kept clear.

e. For manually operated knife switches and similar equipment, the closing or opening motion is positive and rapid.

11. When not required to be open, keep enclosure doors closed to all motor starters, distribution panels, and similar parts.

12. Be sure that electrical machinery has been discharged to ground when secured. The electrical charge which is retained by a machine or ungrounded parts of a machine is sometimes sufficient to cause severe shock.

13. Discharge all capacitors connected in a de-energized circuit prior to touching them. This is done by short circuiting the terminals.

14. Do not use a steel tape or metal-bound rule near electrical equipment.

15. Do not handle loose pipe, angle iron, or other metallic members when working behind switchboards or in the vicinity of any energized equipment whose current-carrying parts are exposed.

16. Use only rubber or insulated hose in portable air lines for blowing out electrical equipment. Be sure the air is free from water and the air pressure is low.

17. Ground all machines and mounting apparatus to the hull. On wooden vessels, ground such apparatus to a ground wire that connects all metal fittings to a plate on the ship's bottom. Insulation breakdowns from a circuit to an ungrounded machine or mounting apparatus will not show on routine ground tests.

18. In drydock take steps to see that the ship's hull is grounded to the dock at several points through its entire length.

19. Provide rubber mats at switchboards, test panels, and in damage control kits for unavoidable work near live circuits.

20. Instruct all electrical ratings in the method of artificial respiration.

Fatalities From Electric Shock

Fatalities or injuries resulting from direct contact with the current-carrying parts of electrical equipment are generally attributed to the victim's carelessness. Improperly maintained equipment on the other hand may result in serious injury or death to the most careful user with responsibility entirely in the hands of individuals charged with maintaining that equipment. Recurrent accidents with a particular design of equipment may, or course, be the fault of the design itself, but this proves true only in a minority of cases. Equipment aboard naval ships is built to the most rigid specifications and undergoes thorough testing before being accepted by the Navy for installation on ships. It is by standard, superior from the standpoint of safety to the majority of equipment supplied for commercial purposes. When properly maintained and properly used it is considered safe to all operating personnel.

From the standpoint of electrical safety, the prevention of breakdowns in insulation must be regarded as the primary function in the maintenance of electrical equipment. Weak insulation, as indicated by a megger, is a danger sign not only for the equipment itself but for the people who have to work with it. Insulation failures often result in short circuits that, when accompanied by high-intensity arcs, may cause injury to personnel working with, or near, the equipment. Equipment not protected with adequate grounding to the ship's structure is exceedingly dangerous when insulation breakdowns occur. Since most of the permanently installed equipment is bolted to steel foundations welded to the hull and are grounded in this way, the precautions of adequate grounding apply almost entirely to portable electrically driven pumps and tools.

The average person cannot conceive that he may receive an electric shock by merely touching the metallic enclosure of a portable appliance or ungrounded tool. Yet such shocks do occur—many times with fatal results. It is imperative therefore that personnel be acquainted with the conditions which render a portable tool deadly to the touch.

First of all, it is to be remembered that while shipboard power systems are of the ungrounded type, leakage currents may be large enough to create a personnel hazard, and zero grounds occur quite frequently in various parts of the system. It is the object of operating personnel to clear these grounds soon after they occur but this is not always possible owing to the necessity of de-energizing vital circuits. When one side of a circuit is grounded, voltage is immediately established between other conductors of the line and ground. A man who stands on the steel deck of a ship and touches any of the ungrounded conductors of this line will be subjected to shock. Suppose this line supplies power to a portable tool, that insulation on the tool has been damaged so that negligible resistence exists between an ungrounded conductor of the power line and the metallic casing of the tool, and that no ground wire is provided to connect the metal case of the tool to the ground. A difference of potential approaching line voltage now exists between the tool casing and ground. When a man decides to use this tool, he inserts his body between casing and ground and thereby establishes the electric circuit to cause a flow of current through his body. This may or may not be his last act depending on the following conditions:

1. The resistance between the grounded conductor and ground. This could range between a solidly grounded conductor with negligible resistance to one with high ground resistance. Even this

will not prevent a fatal shock if numerous radio-interference suppression filters are connected to the line.

2. Contact resistance between an ungrounded conductor and tool casing. Here again the resistance may be of sufficient magnitude to keep the current within safe limits.

3. Contact resistance as determined by moisture conditions, perspiration, and other factors between the tool casing and the hand that holds the tool.

None of these resistances or combination of resistances can be depended upon to act favorably toward sparing the life of a man who happens to use a ungrounded tool that has insulation defects. Adequate grounding is the only safe way of operating portable electrical equipment. This is evidenced by Navy specifications for portable tools which require the electric cord for the tool to be provided with a distinctively marked wire, in addition to the conductors, for supplying power to the tool. The end of this wire within the tool is connected to the metal housing; the other end should be grounded; that is; connected to the ship's metal structure. Particular types of Navy standard receptacles and plugs are available to facilitate the ground connection. These have three contacts for d-c and 115-volt, single-phase a-c circuits and four for 450-volt, three-phase a-c circuits. The extra contact in each receptacle is connected to the ship's structure so that when the plug is properly installed on the tool cord and is plugged into the receptacle, the metal case and handle of the tool are adequately grounded.

When grounded-type receptacles are not available in the spaces where the tool is to be used, other types of plugs and receptacles may be used if the ground lead in the tool cord is connected to the ship's metal structure by other methods. A spring clip fastened on to a convenient nut or bolt is very often a convenient method for securing a tool's ground wire to the ship's structure. Where the tool cord does not include an extra wire for grounding, an additional wire should be obtained and connected between the metal housing of the tool and the ship's metal structure. If the tool housing has two or more conducting parts that are not electrically connected, each should be connected to the ground wire. When the ground connection is made by means other than a contact in the plug and receptacle, care should be taken to secure good contact between the ground wire and the metal to which it is connected by scraping any paint away and scratching a clean surface. The ground connection should be made before inserting the power-supply connecting plug, and the plug should be removed before removing the ground connection. Frequent inspection and check of the connections in portable electric tools should be made to assure that the supply cord and its connections within the tool are suitably insulated and that the ground connection is intact.

It should be observed that a ground connection in order to be effective in preventing any accident with a portable tool must be of low resistance. The term *low resistance* is used instead of low impedance, since it is assumed that any ground connection will have negligible reactance to the flow of alternating current. If a ground connection having appreciable resistance is installed, it will defeat the purpose of such a connection. It must be emphasized, therefore, that the ground wire and its connections to tool casing and ship's structure should provide a low-resistance path to ground. This should be in the order of a very small fraction of an ohm if complete protection is to be assured. Low-resistance ground wires are the means of insuring that any difference in potential that might develop between a tool casing and ground will be small enough to be negligible where the safety of personnel from shock is concerned.

In the installation of the grounded plugs and receptacles, bear in mind that correct connections are absolutely essential for safety. An extremely hazardous condition arises if the ground wire is connected to a contact that touches either side of the power line. Line and ground contacts should be identified correctly and cables should be connected to plugs with the greatest care, and a check made to see that there are no loose strands of copper which may accidentally connect the ground wire to either side of the line. Finally the work should be tested after the connections have been made but before inserting the plug in the receptacle.

Conduct this test with a megger or insulation tester, as follows: With the switch of the tool in the "On" position, connect one megger lead to the exposed metal case of the motor equipment and the other megger lead to the ground terminal of the plug. Measure the insulation resistance. It should be zero. Then with one megger lead still connected to the metal case of the equipment, shift the other megger lead to either line

terminal of the plug and measure the resistance. It will be normal insulation resistance (usually well in excess of 1 megohm) if the ground wire is connected correctly. Repeat with one megger lead still connected to the metal case of the equipment and with the other megger lead connected to the other line terminal of the plug (or to each of the other line terminals if there are more than two). There should be normal insulation resistance in each case if the ground wire is connected correctly and the insulation on the tool and cord is in good condition.

This test should also be made on all portable tools and equipment not previously tested in this way, even though they may have been used before without trouble. Prior use, in itself, is not enough to establish that connections are correct. Other conditions may have prevented shock when the equipment was previously used.

A considerable amount of emphasis has been placed thus far on safety as applied to portable tools. This emphasis is justified by an examination, the records of shipboard electrical fatalities for the years 1946, 1947, and 1948 (through June). Out of a total of 11 fatal accidents, portable equipment accounted for 5, or almost 50 per cent. Examination of specific accidents illustrates most vividly the results of disregarding some of the safety precautions for portable tools as pointed out in the foregoing discussion.

In one case, a man after repairing a portable wire-brushing machine, plugged it in to try it out; as a result he was fatally shocked. It was found that in reassembling the tool, a wire in the terminal box had been laid so that one of the threaded-cover securing bolts scraped the insulation off, permitting current to flow to the terminal-box cover. The plug had been renewed with a light-duty household-type plug. The ground wire was properly connected in the terminal box, but was not connected to ground at the plug end of the power cable. In this situation personnel failed to observe the following safety precautions:

1. To use a standard Navy-type plug.
2. To make a ground connection.
3. To test the tool for insulation resistance to ground and integrity of ground connection, before plugging it in to try it out.

In another case a man was killed when he touched a portable submersible bilge pump. After being repaired, the pump was tested without accident, and found to run. But no test had been made to check insulation resistance to ground and correctness of ground connection. After the accident it was found that phase A of the power supply was connected to the ground terminal on the motor terminal block, and that the ground wire was connected to terminal A of the motor. The motor ran when it was tested, but it was none the less connected improperly and was deadly.

Still another case involved a portable drill. The man using the drill received two nonfatal shocks before the fatal shock, one in the morning when his hands were bare, and another in the afternoon when he wore a pair of greasy gloves. After the second shock he wore a pair of clean gloves for a time, but ultimately discarded these and was working with bare hands when late in the afternoon he picked up the drill and was fatally shocked. Mistake was piled upon mistake to lead to a fatal conclusion. The first mistake was made by the man who should have tested but did not test the drill for insulation resistance and soundness of ground connection before it was put into use. The second mistake was made by the user of the drill, who, after receiving a nonfatal shock while working with bare hands, failed to have the drill repaired and merely put on greasy gloves. The third mistake was made by this man when he received a nonfatal shock while wearing greasy gloves. It was still not too late to fix the drill, but all that he seems to have done was to shift from greasy to clean gloves. And then he made one more mistake. He discarded his clean gloves probably while the drill was not in use, and picked up the drill with bare hands. The result: a man was killed in an accident that could have been avoided had he paid proper attention to the warnings preceding it.

Electric shock from portable tools is a matter of concern not only to electricians who are in a better position to understand the hazards associated with the use of such tools but also to any man aboard ship engaged in making repairs. All hands should therefore be warned of the dangers involved when the tools are improperly maintained and the precautions of ground connections are not observed. Other departments must be cautioned to send any tools under their cognizance to the electrical shop for check-up at regular intervals and electricians must make sure that the tool is completely safe for use before allowing it to be returned.

Fire Prevention

Oily waste, papers, and other inflammable materials behind switchboards or near other exposed live parts are an invitation to fires that are a hazard to personnel safety on any ship. Careless dropping of tools or any loose metallic material across the buswork of switchboards can cause short circuits of great intensity. The resulting arc can cause serious injury or death to personnel in the near vicinity. Electric arcs, even from normal switching or from brush sparking create dangers of explosion in compartments containing inflammable vapors. Where compartments may be normally subject to this condition from time to time, explosion-proof enclosures are incorporated as a protective feature of the equipment. It is possible, however, that other compartments on the ship that are not protected in this way may accumulate flammable vapors, thus ignition of any kind becomes dangerous. Electrical equipment that may be the source of ignition should then be de-energized from switches outside the contaminated space or spaces.

A few simple precautions against injury or death from fire, electric arcs, and explosions are listed as follows:

1. Keep space back of switchboard clean and free from gear or obstruction.

2. Do not work over energized bus where there is a chance of dropping tools or any other metallic material and creating serious short circuits.

3. Use of alcohol for cleaning electrical equipment should be avoided and it should never be used on energized equipment or near electrical equipment from which a spark is possible.

4. Gasoline, benzine, ether, energine, and similar flammable cleaning fluids should never be used on electrical apparatus, even though de-energized.

5. If open-type electrical apparatus or equipment not suitably protected with an explosion-proof enclosure is in operation when the presence of explosive vapor is detected, the apparatus shall be de-energized by means of switches located outside the contaminated space.

FIGHTING ELECTRICAL FIRES

An electrical fire or a fire near energized electrical equipment should be handled in accordance with specialized procedures outlined as follows:

1. De-energize the circuit and shift to stand-by equipment.
2. Report the fire.
3. Extinguish the fire with carbon dioxide.

Carbon dioxide is the preferred fire extinguisher for use on electrical fires. It is a noncorrosive gas that does not damage cables or equipment. It is nonconducting, and the stream of carbon dioxide from an extinguisher can be directed against energized circuits without danger of shock.

A stream of salt water or foam directed against an energized circuit can conduct current to fire fighters and shock them. The same danger is present, though to a lesser extent, when fresh water is used. Extreme care must, therefore, be used when employing water-type extinguishers around energized electrical circuits.

Equipment wet with salt water or foam is more difficult to recondition than if fresh water is used, and much more difficult than if carbon dioxide is used as the extinguisher. Consequently, while water or foam may of necessity have to be used on electrical equipment to prevent a disastrous fire, it is a decided advantage if the fire can be extinguished with carbon dioxide alone.

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